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Geochemical Analysis and Interpretation of Ground Water Data Collected as part of the Anaconda Company Bluewater Uranium Mill Site Investigation (CERCLIS ID NMD007106891) and San Mateo Creek Site Legacy Uranium Sites Investigation (CERCLIS ID NMN00060684)

McKinley and Cibola County, New Mexico

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List of Abbreviations and Symbols

%:	percent
o/oo:	per mil
>:	greater than
<:	less than
δ:	delta units

^{2}H:	deuterium
^{3}H:	tritium
^{13}C:	carbon-13
^{18}O:	oxygen-18
^{34}S:	sulfur-34
^{210}Pb:	Lead-210
^{210}Po:	Polonium-210
^{230}Th:	Thorium-230
^{232}Th:	Thorium-232
^{234}U:	Uranium-234
^{235}U:	Uranium-235
^{238}U:	Uranium-238

ACL:	Alternate Concentration Limits
AEC:	Atomic Energy Commission
Ag:	Silver
Al:	Aluminum
a.k.a.:	Also known as
Ar:	Argon
AR:	alpha-recoil
ARCO:	Atlantic Richfield Company
As:	Arsenic
Ba:	Barium
BaCl:	barium chloride
$BaSO_4$:	barium sulfate
Be:	Beryllium
BW:	Bluewater
BW-##:	Bluewater – sample number
C:	Carbon
Ca:	Calcium
$CaCO_3$:	calcite
$CaSO_4 * 2H_2O$:	gypsum
Cd:	Cadmium
CERCLA:	Comprehensive Environmental Response, Compensation, and Liability Act
Cl:	chloride
CLP:	Contract Laboratory Program
Co:	Cobalt
CO_2:	Carbon dioxide
CO_3:	carbonate
Cr:	Chromium
Cu:	Copper
D:	deuterium
DO:	dissolved oxygen
DOE:	U.S. Department of Energy
e.g.:	*Exempli gratia*, 'for example'
EPA:	U.S. Environmental Protection Agency

Fe:	Iron sulfide
FeS_2:	pyrite
$FeSe_2$:	ferroselite
GMD:	Grants Mining District
GWQB:	Ground Water Quality Bureau
H:	Hydrogen
H_2CO_3:	carbonic acid
H_2S:	sulfide
HCO_3:	bicarbonate
He:	Helium
Hg:	Mercury
HMC:	Homestake Mining Company Superfund Site
HUC:	Hydrologic Unit Code
I-40:	Interstate-40
i.e.:	*id est* or that is
ICP-MS:	inductively coupled-mass spectrometer
Jmw:	Jurassic Morrison Formation, Westwater Canyon Member
K:	Potassium
Kd:	Cretaceous Dakota Sandstone
Kr:	Krypton
LASL:	Los Alamos Scientific Laboratory
LANL:	Los Alamos National Laboratory
meq/l:	milliequivalents per liter
Mg:	Magnesium
mg/kg:	milligrams per kilograms
mg/l:	milligrams per liter
Mn:	Manganese
Mo:	Molybdenum
MPC:	maximum permissible concentration
MRGB:	Middle Rio Grande Basin
MWL:	meteoric water line
N:	North
Na:	Sodium
NaCl:	sodium chloride
Ne:	Neon
NH_4:	ammonium
NH_4+NO_3:	ammonium nitrate
Ni:	Nickel
NMED:	New Mexico Environment Department
NMWQCC:	New Mexico Water Quality Control Commission
NO_3:	Nitrate
NO_3+NO_2,	Nitrate plus nitrite
NPDES:	National Pollution Discharge Elimination System
NPL:	National Priority List
NRC:	U.S. Nuclear Regulatory Agency
NURE:	National Uranium Resource Evaluation
O:	Oxygen
ORP:	oxidation-reduction potential
pCi/l:	picoCuries per liter
PCB:	polychlorinated biphenyls
Pb:	Lead
pH:	minus the decimal logarthim of the hydrogen ion activity in a solution
ppb:	parts per billion
ppm:	parts per million

Qal:	Quaternary alluvial aquifer
QAPP:	Quality Assurance Project Plan
QMP:	Quality Management Plan
R:	Range (as in Township Range Section)
Ra:	Radium
S:	Section (as in Township Range Section)
S:	Sulfer
SAG:	San Andres-Glorieta aquifer
Sb:	Tin
Se:	Selenium
SeO_3:	selenite
SeO_4:	selenate
SI:	Site Investigation
SLD:	New Mexico State Laboratory Division
SMC:	San Mateo Creek
SMC-##:	San Mateo Creek – sample number
SMOW:	standard mean ocean water
SO_4:	Sulfate
SOS:	Superfund Oversight Section
SWL:	static water level
T:	Township (as in Township Range Section)
TDS:	Total Dissolved Solids
Th:	Thorium
Tl:	Thallium
Tr:	Triassic Formation
U:	Uranium
U(nat):	Uranium (natural)
U.S.C.:	United States Code
ug/l:	microgram per liter
ug/g:	micrograms per gram
U_3O_8:	yellowcake
US:	United States
UNM:	University of New Mexico
V:	Vanadium
W:	West
Xe:	Xenon
Zn:	Zinc

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Executive Summary

The Grants Mining District (GMD) in New Mexico produced more uranium (U) than any other district in the world during the period of 1951-1980. In the largest sub-district, Ambrosia Lake, there are 96 documented former producing mines and four mills, some of which have documented contaminant releases. Investigation of the isotopic ratios of C, O, H, S, and the U series from a limited number of ground water samples from two areas within the GMD were analyzed to determine if discrepancies in the isotopic ratios could distinguish background water quality from ground water impacted by releases from U mining and milling operations. This method of systematic investigation is called "environmental forensics." Utilization of environmental forensic methods for determining specific geochemical properties of the ground water was expected to more accurately define baseline water quality conditions in ground water sources with and without possible anthropogenic impacts. The ground water samples were collected as part of the site investigations of Anaconda Bluewater Mill and the San Mateo Creek Basin under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended, 42 United States Code (U.S.C.) §§ 9601 to 9675 (CERCLA).

The 3,300-acre Anaconda Company Bluewater Uranium Mill site, now called the Bluewater Disposal site by the U.S. Department of Energy (DOE), is located in the southwest corner of the SMC basin in north-central Cibola County. Anaconda processed ore from the nearby Jackpile mine in Paguate, New Mexico at the mill from 1953-1982. This mill operated a carbonate-leach process with a capacity of 300 tons per day until 1957. An acid-leach mill was operated from 1957-1982, reaching a production capacity of 6,000 tons per day in 1978. A waste water disposal well was used to inject millions of gallons of acidic mill raffinate water into formations below the San Andres-Glorieta aquifer. The Atlantic Richfield Company (ARCO) reclaimed the Bluewater Mill site between 1991 and 1995, which included ground water remedial activities to address contamination in the alluvial and San Andres Limestone-Glorieta Sandstone aquifer. Title to the site was transferred to the DOE for long-term stewardship in 1997. Ground water contaminants that may be associated with the site, as derived from historical documentation; include radium (Ra), uranium (U), nitrate (NO_3), chloride (Cl), molybdenum (Mo), asbestos, selenium (Se), magnesium (Mg), thorium (Th), aluminum (Al), manganese (Mn), iron (Fe), and polychlorinated biphenols (PCB).

The San Mateo Creek (SMC) basin comprises approximately 321 square miles within the Rio San Jose drainage basin in McKinley and Cibola counties, New Mexico, and includes the Ambrosia Lake mining sub-district. In 2008-2009 the New Mexico Environment Department (NMED) performed a Site Investigation, which included the collection, analysis, and evaluation of ground water samples to characterize and evaluate the impacts of legacy U mining and milling activities on the SMC regional ground water system. Aquifers within the SMC ground water system include the Permian age San Andres Limestone-Glorieta Sandstone (SAG); the Triassic Chinle Formation; the Jurassic Morrison Formation, the Cretaceous Dakota Sandstone, Tertiary basalt flows, and Quaternary alluvial material. The SAG is an important agricultural, industrial, municipal, and private water supply source in the area. Table ES-1 summarizes geochemical distinctions between the alluvial and bedrock aquifers in the San Mateo Creek Basin.

From the Bluewater Mill site, the SAG dips northeast to the nearby and downgradient Homestake Mining Company U mill Superfund site (HMC). HMC is located in a hydrogeologically complex area where the SAG and Alluvial aquifers may be hydraulically interconnected, and the source of increasing concentrations upgradient is not clear from existing monitoring data. Alluvial water quality upgradient of HMC appears to be impacted by releases from legacy sites in the northern part of the SMC basin around the Ambrosia Lake area. The SMC alluvial system south of HMC has been impacted by contamination from HMC. The Alluvial aquifer in the vicinity of HMC is underlain by the Triassic Chinle Formation, which is a predominantly thick sandstone, siltstone, and shale formation. The SAG regional aquifer underlies the Chinle Formation in this area.

In 2008, NMED conducted a Site Investigation (SI) of the Bluewater Mill site, collecting 33 water samples from wells known or assumed to be completed in the SAG both up and down gradient of the site. In 2009 NMED conducted an SI of the SMC basin, collecting 29 water samples from various alluvial and bedrock wells in the SMC basin, primarily upgradient of HMC. Sampling included duplicates and blanks for various quality assurance-control protocols. The samples were analyzed for field parameters, dissolved major ions, dissolved metals, and radioactivity. A limited number of samples from selected wells in the Bluewater Mill and SMC SI areas were collected for laboratory analysis of ^{13}C, ^{2}H, ^{18}O, ^{34}S, ^{238}U, ^{235}U, and ^{234}U. In concert with laboratory measurements of the dissolved concentrations of metals and major ions and radiochemistry (gross alpha/beta, Ra, and total U), isotopic data on ratios of C, O, H, S, and the U series were evaluated to determine whether the isotopic signatures could help distinguish background water quality from ground water impacted by releases from U mining and milling operations.

Historical water quality data from previous investigations in the SMC area is extremely sparse because sampling was conducted intermittently, and the number of parameters for which samples were analyzed was often limited and geochemically inadequate to distinguish indications of anthropogenic contribution. During the period of active operation, water samples from U mine dewatering and mill discharges to drainages were elevated in total dissolved solids (TDS); select compounds like NO_3 and SO_4; trace elements like As, Se, Cl, Fe, Mo, Ra, and U; and radioactivity (gross alpha/beta). Depending on the discharge source, the pH of the discharge water was also more alkaline or more acidic than the natural ground water in the area. Baseline sampling to determine the natural, background concentrations of ground water quality parameters prior to legacy U mining and milling operations was not performed, and this drawback continues to hamper ongoing quantitative geochemical assessments of legacy impacts on ground water.

A properly designed network of monitoring wells to characterize and assess the natural concentrations in ground water and at potential release sites in the SMC basin does not exist. Many of the existing wells that were sampled in these investigations were not optimally located to assess the geochemistry of the basin at points along the presumed flow path from up gradient to down gradient. Many of the well construction completions were unavailable and the water producing interval(s) unknown. Nevertheless, the number of well locations sampled, the area encompassed, and the parameters measured in the samples by laboratory analysis provided a substantial amount of data to characterize and evaluate the ground water quality in the SMC area. The Bluewater Mill SI sample data are mostly considered to be representative of natural conditions without any legacy U components for the SAG, whereas, the SMC SI sample data are considered to include both unimpacted ground water as well as ground water impacted by legacy U activities. Unusual concentrations of geochemical parameters were observed in the Bluewater Mill site monitoring wells, which are assumed to draw water from the SAG that is contaminated by discharges from the legacy milling operations, particularly the unlined waste water evaporation ponds, and possibly a deep injection waste water disposal well.

Evaluation of the water sample analyte concentrations compared to the federal Environmental Protection Agency (EPA) drinking water and state ground water quality standards indicated 38 samples had a total of 107 concentrations that exceeded one or more standards. In 16 of 33 Bluewater Mill SI samples, EPA and state standards were exceeded for: NO_3+NO_2 (1); gross alpha (2); pH (2); TDS (14); Cl (3); SO_4 (3); Fe (2); Mn (1); and U (1). In 22 of 29 the SMC SI samples, EPA and state standards were exceeded for: As (7); NO_3+NO_2 (5); Se (8); gross alpha (16); gross beta (4); pH (1); TDS (12); SO_4 (10); F (1); Fe (2); and U (12).

TDS content in water samples ranged from 254 to 4,720 mg/l and averaged about 1,200 mg/l. TDS concentrations were slightly higher on average in the SMC SI sample set than in the Bluewater Mill SI sample set (1,432 and 1,051 mg/l, respectively). Field pH ranged from 5.40 to 10.21 and averaged about 7.3. Field pH is slightly higher on average in the SMC SI samples than in the Bluewater Mill SI samples (7.58 and 7.08, respectively). Based on the TDS concentration of the water, the ground water is simply classified as fresh to brackish water. TDS concentrations generally increased from west to east across the Bluewater Mill SI sampling area, and from north to south across the SMC SI sampling area. The sample

set order of major ion concentrations from high to low was: $SO_4>HCO_3>Ca>Na>Mg>Cl$ for the Bluewater SI samples, and $SO_4>Na>HCO_3>Ca>Mg>Cl$ for the SMC SI samples. NO_3+NO_2 concentrations ranged from less than one to 22.8 mg/l in the SMC SI samples, and from less than one to 10.0 mg/l in the Bluewater SI samples. Most Bluewater SI water samples were a CaMg-Na/HCO_3-Cl-SO_4 water type, whereas, most water samples in the SMC SI set were a CaMg-Na/Cl-SO_4 water type. The Alluvial aquifer water samples in the SMC SI set were typically the most elevated in TDS concentrations, whereas, the samples from wells completed in bedrock units had lower overall TDS concentrations. Two areas of well locations were observed for elevated TDS: the group of wells above HMC; and the group of wells around the junction of state highways 605-509.

Many concentrations of minor constituents and trace metals were reported at low levels (less than 1.0 mg/l) or below the laboratory reporting limit (2 - 20 ug/l average depending on analyte). Seven trace metals in the Bluewater SI sample set (Ag, Al, Be, Cd, Co, Sb, and Tl) measured less than the laboratory reporting limit in all samples. Twelve trace metals in the SMC SI sample set (Ag, Al, Be, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, and Tl) reported less than the laboratory reporting limit in most samples. Thirteen trace metals reported a combination of less than the laboratory reporting limit and actual values in both sample sets (As, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, U, V, and Zn). The number of sample trace metal results measured at less than the laboratory reporting limit is a significant disadvantage for evaluation of geochemical data and observed spatial geochemical changes along a presumed ground water flow path. Five trace elements were used in the analysis of the Bluewater Mill SI sample data (As, Ba, Se, Zn, and U) and seven trace elements were used in the analysis of the SMC SI sample data (As, Ba, Mn, Se, V, Zn, and U). The order of trace element concentrations, from high to low was: Zn>Ba>U>Se>As in the Bluewater SI samples, and Fe>Zn>Se>U>Mn>Ba>As in the SMC SI samples. Dissolved Se averaged 8.8 and 101.8 ug/l in the Bluewater and SMC SI sample sets, respectively. The concentration of dissolved U ranged from a low of less than the laboratory reporting limit (<2 ug/l) to a high of 53.3 ug/l in the Bluewater SI sample set, and from less than the laboratory reporting limit to a high of 240.0 ug/l in the SMC SI sample set. Dissolved U concentrations averaged 12.4 and 67.3 ug/l in the Bluewater and SMC SI sample sets, respectively. Elevated concentrations of dissolved U were observed to have a correlation with elevated levels of dissolved Se at well locations assumed to produce from the Alluvial aquifer.

Gross alpha activity ranged from less than the laboratory reporting limit (<0.1 pCi/l) to 29 pCi/l in the Bluewater Mill SI samples. Gross alpha activity ranged from less than detection to 128.3 pCi/l in the SMC SI samples. Gross beta activity ranged from 0.4 to 16.7 pCi/l in the Bluewater SI samples. Gross beta activity ranged from 2.0 to 83.0 pCi/l in the SMC SI samples. Gross alpha/beta activity averaged 8.3/8.1 and 34.2/23.4 pCi/l, respectively, in the Bluewater and SMC SI sample sets. Most water samples had activity values for other radionuclides that were less than 1.0 pCi/l in both the Bluewater and SMC SI sample sets. $^{226}Ra/\ ^{228}Ra$ activity averaged 0.10/0.41 and 0.20/0.78 pCi/l, respectively in the Bluewater and SMC SI sample sets. The highest $^{226}Ra/\ ^{228}Ra$ activity values (2.90/3.91 pCi/l) was from a well located west of the state highway 605-509 junction and interpreted to produce water from a bedrock unit because of the absence of dissolved Se. Ra was observed to be an unreliable indicator of legacy U operations discharges because the activities measured in the samples were low overall, and the radionuclide does not appear to move very far from the discharge source.

Ground water impacts from uranium mill raffinate waste water may be detected through evaluation of the activity ratio (AR), $^{234}U:^{238}U$. Relying heavily on $^{234}U:^{238}U$ AR data values (approximately 1.0) raffinate waste water, as well as on other concepts from an investigation of a mill site in southwestern Colorado, some of the Bluewater and SMC SI samples are interpreted to contain a possible anthropogenic component because of their low AR values and high dissolved U concentrations. Evaluation of U isotopic data provided an interpretation to separate ground water samples into three simple categories: 1) background; 2) a mixture of background and U mill raffinate impacts; and 3) U mill raffinate impacts. Additional proof-of-concept testing is required to validate the hypothesis that the $^{234}U:^{238}U$ AR can be used to indicate an anthropogenic component in the ground water. Most of the samples with the low U AR values and elevated dissolved U concentrations are assumed to be from wells that produce from the

Alluvial aquifer. Interpretation of ^{34}S isotope data relies heavily on delta $(\delta)^{34}$S data from a 1963 study of U ore samples from the Ambrosia Lake area. The Bluewater SI δ^{34}S sample data suggest the source of S is from a marine limestone origin, whereas the SMC SI δ^{34}S sample data suggest a source of sulfur from a biogenic, reducing environment such as would be associated with the classic model for U roll-front deposit. Again, lacking in direct geochemical evidence, a proof-of-concept test is required to validate such an interpretation. The ^{13}C isotope data were not evaluated at this time because the C cycle in the environment is complex, requiring more geochemical expertise to perform a substantive evaluation. The limited number of O and H isotope samples indicated that there is range of isotopic ratios for these elements, likely reflecting a complex hydrologic ground water system from depleted (winter precipitation recharge?) to enriched (evaporated?) sources. The absence of isotopic data from all wells that were sampled for these investigations, and from recharge sources to the ground water system precluded a more thorough interpretation of the hydrogeochemistry in the SMC basin.

The Bluewater and SMC ground water investigations have provided a more extensive base line of water quality parameters and geochemistry for future investigations and monitoring of legacy U impacts on ground water in the GMD. The SAG appears to be a largely unimpacted ground water supply except possibly at a few well locations near former mill sites. The Alluvial aquifer in the SMC basin appears to contain elevated levels of TDS, metals, and radioactivity from legacy activities, but the degree of interaction between the alluvial and deep bedrock aquifers is unknown. The interpretation of anthropogenic components at some well locations from the utilization of select isotopes in these investigations requires proof-of-concept testing to validate the application of this technique. Many more evaluations of the data from these investigations may be possible to help gain further understanding of the ground water system. Some of the weaknesses identified in these investigations that hamper a more comprehensive understanding of the ground water system in the SMC basin include: 1) lack of properly sited and constructed wells to monitor ground water around and down gradient of legacy U sites; 2) lack of current static water level contour maps to evaluate seasonal and annual flow direction and gradient changes in area aquifers; 3) lack of aquifer pump test data to determine aquifer properties and the associated geologic influences to ground water flow; 4) lack of detailed geologic and stratigraphic information to support the creation of accurate cross sections at important transect locations; and 5) need for an integrated and comprehensive basin wide plan for characterization and assessment of legacy U site impacts to the ground water system in the GMD.

Table ES-1: Summary of Geochemical Distinctions between the Alluvial and Bedrock Aquifers in the San Mateo Creek Basin.

Criteria	Alluvial Aquifer	Bedrock Aquifer
TDS	More brackish water (> 1,000 mg/l); 1,000 – 3,000 + mg/l range	More fresh water (< 1,000 mg/l); some Morrison Formation/West Water Canyon TDS = 1,000 – 2,000 mg/l range.
Stiff diagrams	Larger than bedrock Stiff w/ longer tails	Smaller Stiff w/ shorter tails
Major ions	$Ca > Na$; $SO_4 > HCO_3$	$Na > Ca$; $HCO_3 > SO_4$
Piper diagrams	Predominantly $CaMg-Na/HCO_3-SO_4$ water-type	Mixed ion water-type; $Na-CaMg/SO_4-HCO_3$
NO_2+NO_3	Usually >/= 5 mg/l or 10-20 mg/l	Usually < 1 mg/l or < 5 mg/l
NO_2+NO_3	More shallow = higher concentration; increases along flow path	Decreases w/ depth of water bearing zone
Arsenic	> 20 ug/l	< 5 ug/l
Selenium	> 80 ug/l; some > 250 ug/l	< 80 ug/l
Uranium	> 100 ug/l	< 50 ug/l
^{234}U:^{238}U Activity Ratio (AR)	Low AR (1-2) & U > 150 ug/l SMC-11, -12, -13, -26, & -33 are impacted based on this criteria (see Figure 35 in report).	AR > 2 & U < 75 ug/l
δ^2H; $\delta^{18}O$; $\delta^{13}C$	Slightly more enriched (contains more of heavier isotopes than bedrock)	Slightly less enriched
$\delta^{34}S$	More depleted in heavier isotope than bedrock	Slightly more enriched than alluvial water
Distance	Within boundaries of or close to alluvial channel	Far away from or out of alluvial channel boundaries
Depth to Static Water Level (SWL)	Generally 30-80 feet	Greater than 80 feet
Well depth	Generally < 100-130 feet	Generally > 150 – several 100 feet
Sample/well numbers that meet most criteria	SMC-08, -09, -10, -11, -12, -13, -14, -17, -26, -33, & -34.	SMC-07, -20, -23, -24, & -28.
Sample/well numbers that meet a few criteria	SMC-21	SMC-03, -04, -05, -16, -18, -22, -25, -28, -30, & -32.

1.0   Introduction and Site Location

The Grants Mining District (GMD) in New Mexico produced more uranium than any other district in the world during the period of 1951-1980. In the largest sub-district, Ambrosia Lake, there are 96 documented former producing mines and four mills, some of which have documented contaminant releases. Under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended, 42 United States Code (U.S.C.) §§ 9601 to 9675 (CERCLA), the New Mexico Environment Department (NMED) Superfund Oversight Section (SOS) conducted a Site Investigation (SI) at the Anaconda Company Bluewater Uranium mill site, Cibola County, New Mexico (CERCLIS ID NMD007106891). Additionally the NMED SOS also conducted an SI of the legacy uranium sites within the San Mateo Creek Basin in Cibola and McKinley Counties, New Mexico (CERCLIS ID NMN00060684; NMED, 2009). These investigations gathered information and acquired sample data that was used evaluate the sites to determine if threats to human health and the environment exist such that further action under CERCLA is warranted (NMED, 2008).

The Grants Mining District, which is located in the northwestern corner of New Mexico, produced more uranium than any other district in the world during the period of 1951-1980 (McLemore and Chenoweth, 1989). Also known as the Grants Mineral Belt, the GMD extends from the Laguna area to a few miles east of Gallup, New Mexico, (about 100 miles). Four mining sub-districts are located within the GMD: Ambrosia Lake, Laguna, Marquez, and Bernabe Montano (NMED, 2009).   These four sub-districts contain a total of 114 former uranium mines and 5 former uranium mills. In the largest sub-district, Ambrosia Lake, 96 former producing mines and 4 mills have been documented (NMED, 2009). Some of the legacy uranium mines and mill sites in the Ambrosia Lake sub-district have documented contaminant releases and other sites have the potential to release contaminants to the environment. The objective of investigation of the Ambrosia Lake sub-district is to determine if releases to air, soil, surface, and ground water systems have occurred, and if they pose a threat to human health and the environment.

The NMED conducted separate site investigations of the Anaconda Bluewater Mill and the San Mateo Creek mid and upper basin between 2008 and 2009. These investigations comprised analysis of samples from existing private wells. This report describes the investigation, data interpretation, and conclusions from ground water sample analyses collected from wells in the GMD, Ambrosia Lake sub-district area in northwestern New Mexico. NMED performed this investigation and analysis of water sample laboratory results in order to characterize and evaluate the impacts of legacy uranium mining and milling activities on the SMC regional ground water system. This report also contains recommendations for future work to fill data gaps to further a comprehensive understanding of the hydrogeology and geochemistry of the SMC basin in order to identify and characterize legacy uranium environmental impacts.

This report utilizes historical and new information from laboratory testing of well water samples to analyze the hydrochemistry of the ground water system. Variations in the hydrochemistry of the water samples are used to determine if there are indications of anthropogenic impacts to ground water from the Bluewater Mill Site and upgradient sites in the SMC area.

The SMC basin (Hydrologic Unit Code [HUC] 1302020703), by which the boundary of the Site is defined, comprises approximately 321 square miles within the Rio San Jose drainage basin in McKinley and Cibola counties, New Mexico (NMED, 2009). This basin is located within the GMD, which is an area of uranium mineralization occurrence approximately 100 miles long and 25 miles wide encompassing portions of McKinley, Cibola, Sandoval and Bernalillo counties, and includes the Ambrosia Lake mining sub-district. Main access into the Site is provided by Interstate 40, New Mexico State Road 122 (historic Route 66), and New Mexico State Roads 605 and 509. Figure 1 presents a location map of the GMD-SMC investigation area.

1.1   Anaconda Company Bluewater Uranium Mill Site

The 3,300-acre Anaconda Company Bluewater Uranium Mill Site, which now is called the Bluewater Disposal Site by the U.S. Department of Energy (DOE), is located in the southwest corner of the San Mateo Creek basin in north-central Cibola County (NMED, 2008). The latitude of the Site is 35° 15-17' north (N); the longitude is 107° 55-57' west (W). The Bluewater Disposal Site is located in sections 7, 8, 17, 18, and 19 of Township (T) 12 N, Range (R) 10 W, and sections 12, 13, and 24, T 12 N, R 11 W, New Mexico Principal Meridian, and is approximately nine air miles northwest of Grants and about 1.5 miles northeast of the village of Bluewater. New Mexico State Highway 334, which intersects State Highway 122, provides access to the Site.

The Anaconda Copper Company, which was succeeded by ARCO, conducted uranium milling operations at the Site between 1953 and 1982 (NMED, 2008). The Anaconda Copper Company built the Bluewater mill in 1953 to process ore from the Jackpile mine. This mill used a carbonate-leach process with a capacity of 300 tons per day and operated until 1957. An acid-leach mill was operated from 1957 through 1982, reaching a production capacity of 6,000 tons per day in 1978.

ARCO Coal Company reclaimed the Bluewater Site between 1991 and 1995, which included ground water remedial activities to address contamination in the Alluvial and San Andres/Glorieta aquifers. During Site reclamation, polychlorinated biphenyl (PCB) contaminated wastes were discovered onsite; these were encapsulated onsite with permission of the EPA. Title to the Site was transferred to the DOE for long-term stewardship in 1997, after the U.S. Nuclear Regulatory Agency (NRC) approved ARCO's application for Alternate Concentration Limits (ACL) for these aquifers in 1996. Ground water contaminants that may be associated with the Site, as derived from historical documentation, include $^{226+228}$Ra, U, NO$_3$, Cl, Mo, asbestos, Se, Mg, Th, Al, Mn, Fe, and PCBs.

The community of Bluewater is located approximately 2.5 miles east of the Site. The Bluewater municipal water system (NM3525033) has one active supply well completed in the San Andres aquifer with 160 service connections for 560 people. The municipal water systems for the communities of Milan and Grants, which are located 7 and 10 miles respectively southeast from the Site and have a collective population of over 10,000, also obtain water from the San Andres aquifer.

Homestake Mining Company is currently remediating the nearby downgradient Homestake Mining Company Superfund Site (CERCLIS ID NMD007860935), a former uranium mill, under the regulation of NRC license SUA-1471, EPA Record of Decision (EPA/ROD/R06/050, 1989) and NMED discharge permit DP-200. The Homestake Mining Company Superfund Site (HMC) was placed on the EPA Superfund National Priority List (NPL) in 1983 primarily due to ground water contamination found in residential wells near the site (EPA, 2006). Ground water monitoring activities for ongoing remediation for the HMC have identified uranium concentrations in the San Andres aquifer which exceed both federal and state drinking water standards. Ground water in the San Andres generally flows eastward away from the Bluewater Site and toward HMC. The San Andres-completed wells with elevated levels of uranium are located upgradient and northwest of HMC. The uranium concentrations are not clearly attributable to contamination from the HMC Site because recharge to eastward-flowing ground water in the San Andres aquifer is west of the HMC Site

1.2   San Mateo Creek Site

The SMC basin contains 85 legacy uranium mines with recorded production and 4 legacy uranium mill sites (NMED, 2009). As discussed previously, one of these mill sites, HMC, is the subject of ground water remediation activities under the jurisdiction of the NRC, EPA and NMED. Background concentrations of constituents of concern (a.k.a., clean-up levels) in four aquifer units impacted by historical HMC activities generally exceed federal and state drinking water standards. The origin of these elevated background contaminant concentrations may be due, in part, to contamination from upgradient legacy uranium mine and mill sites within the basin. Far upgradient geochemical data from HMC suggest that overall alluvial ground water quality relative to drinking water standards is worse than in the

immediate upgradient vicinity of HMC, possibly due to the continuing migration of ground water that is impacted from the high concentration of legacy uranium sites located in this area of the basin.

The southern end of the San Mateo alluvial system has been impacted by contamination from the HMC. Contamination from HMC in this alluvial system generally follows the San Mateo Creek drainage to the south of HMC. Underlying the Alluvial aquifer in this vicinity is the Upper Triassic Chinle Formation, which is a predominantly shale formation 800 feet in thickness. Three aquifer units have been identified in the southern part of the basin within this formation. The highest two aquifers are the Upper and Middle Chinle sandstones. The lowest aquifer, the Lower Chinle, is a fractured shale with variable hydrologic yield of generally poor quality water (i.e. does not meet water quality standards). All three of these aquifers subcrop with the Alluvial aquifer, connecting the Alluvial aquifer and each of the Chinle aquifers hydrologically in the vicinity of the Homestake site. The San Andres regional aquifer underlies the Chinle Formation in this area.

2.0   Ground Water Investigation and Sampling Activities

NMED characterized possible impacts to ground water quality in the SMC basin aquifers through ground water sample analyses for general hydrochemical parameters, total and dissolved metals, and radionuclides concentrations. Table 1 presents the field parameters and laboratory analytes measured in ground water samples for the site investigation of aquifers in the Bluewater and SMC areas, New Mexico. NMED sampled ground water from private residential and monitoring wells completed in the San Andres aquifer within a transect oriented in the presumed direction of ground water flow across the Bluewater Mill Site (i.e., northwest/southeast; see Figure 2). At the upgradient end of the transect, NMED sampled domestic wells that are presumed to be unimpacted by potential contamination from the Bluewater Mill site. The transect included the existing San Andres-completed monitor wells on the Bluewater Mill Site that are used for the DOE's long-term monitoring responsibilities, and San Andres-completed monitor and domestic wells that are both downgradient of the Bluewater Site and cross-gradient of HMC.

Analyses of the 33 well samples from the Bluewater-San Andres Aquifer were performed by the EPA Contract Laboratory Program (CLP) and the New Mexico State Laboratory Division (SLD). Additional samples included 3-5 duplicate samples and trip blanks for quality assurance, in accordance with SOS's Quality Assurance Project Plan (QAPP, 2009) and the Ground Water Quality Bureau (GWQB) Quality Management Plan (QMP, 2008). NMED conducted this field sampling between August 25-28, 2008, and on September 19, 2008. The original sample designation was four letters "BWSI" and a dash followed by the sample number. It was shortened for this report to a two letter abbreviation and number, "BW-##," which stands for "Bluewater" and the "sample number-location."

Between March 31, 2009 and April 4, 2009, NMED sampled ground water from 29 private residential, livestock, and monitoring wells located throughout the San Mateo Creek study area (NMED, 2009). One sample location did not provide enough volume to fill the complete set of sample bottles so only the radiochemistry analysis was performed. One sample location was a repeat sample at a well location from the Bluewater-Milan ground water sampling investigation in 2008. Two field blanks, two equipment blanks, and two duplicate samples were collected for quality assurance, in accordance with SOS's QAPP, 2009 and GWQB QMP, 2008.

Major ions, metals, and radiochemical analyses of the 28 SMC ground water samples were performed by the EPA CLP and SLD. NMED conducted this field sampling between March 31, 2009 and April 4, 2009. The collection of ground water samples included field duplicate, field blank, equipment blank, and unique well location samples that were designated by the three letter abbreviation and number, "SMC-##," (San Mateo Creek – sample number). Figure 3 presents a map of all the ground water sample locations in the San Mateo Creek Basin site investigation area.

Water samples at each private well location were collected from an access point closest to the well head if there was a dedicated pump already installed and operational. A few wells without dedicated pumps required the utilization of a portable submersible pump. Private wells were purged for at least 15 minutes or until field water chemistry parameters stabilized (e.g., pH, conductivity, temperature). Samples were collected in the appropriate containers and preservatives, placed in insulated coolers with ice, and shipped to the laboratories as specified by the CLP. Samples analyzed by SLD also were collected within appropriate containers supplied by SLD, transported to the laboratory in Albuquerque, and submitted for analysis within the specified holding time. All samples collected in this program for CLP analyses utilized chain-of-custody handling procedures.

3.0   Environmental Isotope Sampling and Analysis

A limited number of special samples from select wells in the Bluewater and SMC areas were collected for laboratory analysis of carbon, oxygen, hydrogen, sulfur, and uranium isotopic composition. In concert with laboratory measurements of the dissolved concentrations of metals and major ions and radiochemistry, data on isotopic ratios of carbon, oxygen, hydrogen, sulfur, and the uranium series were expected to help distinguish unimpacted background water quality from impacted water quality due to releases from uranium mining and milling operations. This method of systematic investigation is called "environmental forensics." This type of technique utilizes scientific analyses of sample media to chemically "fingerprint" a suspected hazardous waste release to answer questions of environmental liability, and possibly support a legal argument or enforcement action (Murphy, B. and Morrison, R., 2007). Environmental forensic investigations try to reconstruct past releases and their source(s) by identifying unique geochemical fingerprints that can be legally allocated to a particular event, facility, material, or industry. Utilization of environmental forensic methods for determining specific geochemical properties of the ground water was expected to more accurately define baseline water quality conditions in ground water sources with and without possible anthropogenic impacts. Select samples of ground water were collected by NMED and analyzed by the University of New Mexico, Earth and Planetary Sciences Department Isotopic Laboratory (e.g., ^{13}C, ^{2}H, ^{18}O, and ^{34}S). The university subcontracted a commercial laboratory to analyze for isotopes of uranium (e.g., ^{238}U, ^{235}U, and ^{234}U).

4.0   Hydrogeology of the Bluewater Investigation Area

Previous investigation reports were reviewed for information about the geology, hydrology, water quality, water use, and potential contaminant sources to the regional ground water system. The regional geology of the area has been studied primarily because of the U industry that operated during the early 1950s to mid-1980s. Prior to the full development of U industry, agriculture had been the primary industry in the Bluewater area. More development of ground water was necessary to support U mills, crop irrigation, electric power generating stations, municipalities, and domestic growth in the Bluewater-Grants area.

Murray (1945) made a reconnaissance study of ground water in the area near the town of Bluewater for irrigation and identified three primary aquifers: the basalt, the alluvium, and the Permian limestone and sandstone. The Bluewater Underground Water Basin was declared by the State Engineer on May 21, 1956 to regulate the use of ground water. Gordon (1961) conducted a detailed study of the Bluewater-Grants area to evaluate water quality, declining water levels, and the availability of ground water for future use. West (1972) described the Anaconda Bluewater Uranium Mill waste water well injection program and its impacts on the local ground water system. The EPA assessed the impacts of waste discharges from uranium mining and milling on ground water in the GMD with a focused sampling investigation on the Anaconda, Homestake, and Ambrosia Lake Mill sites (EPA, 1975). Brod and Stone in 1981 described hydrogeology of the Ambrosia Lake-San Mateo area. Gallaher and Cary (1986) described a regional sampling and assessment of the impacts of the uranium industry on surface and shallow ground water conducted by the New Mexico Environmental Improvement Division (predecessor

agency of NMED) from 1977 to 1982. Baldwin and Rankin (1995) described the hydrogeology of Cibola County which included wells completed in aquifer units in the Bluewater-Grants area.

The geologic history of the area consists of various periods of deposition, uplift, erosion, deposition, faulting, and more erosion. Stratigraphic units of sedimentary rock are exposed in the broad valley and adjacent highland mesas around the northern flank of the Zuni Mountains and the volcanic flows surrounding Mount Taylor (Gordon, 1961). Sedimentary units in the valley dip toward the northeast and are often covered by alluvium and basalt flows. Permian age strata from 1,500 to 2,000 feet thick underlie the Bluewater-Grants area. Triassic Chinle formation and Quaternary alluvium and basalt also occur in the area, but these units are generally of very low yield and do not support high yield industrial, municipal, and irrigation ground water use.

The Permian strata contain the important water-bearing aquifers and in ascending order the major units are: the Abo; Yeso; Glorieta; and San Andres formations. The Abo formation (500-800 feet thick) is a reddish brown arkosic or quartzose sandstone and siltstone with conglomerate in the lower part of the formation. The Yeso formation (100-350 feet thick) is primarily a brownish red sandstone with siltstone. The Glorieta formation (125-300 feet thick) is a medium grained, white to light gray or buff sandstone. The San Andres formation (80-150 feet thick) is a massive, generally gray sandy limestone with interbedded sandstone and limestone, and is the major aquifer in the Bluewater-Grants area. After the San Andres limestone was deposited, the area was uplifted and subjected to a long period of erosion during which karst topography was developed having a relief of more than 100 feet into the San Andres surface. Well connected cavernous zones and solution channels have developed in the formation and the aquifer can transmit large quantities of water to wells in many places (Gordon, 1961). During this erosional period at the Permian-Triassic contact, sediments from the base of the Chinle Formation were deposited on the surface, and Triassic sediments filled caverns and sinkholes. The Triassic sediments include debris from the Moenkopi and Chinle Formations which are often composed of reddish-brown siltstone, mudstone, silty and conglomeratic sandstone, and gypsum.

In Cibola County the Glorieta Sandstone and the San Andres Limestone are considered to be one aquifer because of the gradational contact, extensive intertonguing, and the probable substantial hydraulic connection between the two units (Baldwin and Rankin, 1995). Recharge to the San Andres-Glorieta (SAG) aquifer in the Bluewater area occurs primarily from precipitation and runoff along outcrops on the flanks of the Zuni Mountains (Gordon, 1961). Recharge also occurs from precipitation on the alluvium and basalt, from seepage beneath Bluewater Lake and Bluewater Creek (Rio San Jose), from seepage along irrigation canals, and from irrigation water.

The San Andres Limestone is covered by Quaternary material in the Bluewater-Grants area and includes basalt flows and alluvial deposits. The Bluewater basalt underlies a large part of the Bluewater-Grants area. Quaternary alluvium forms a veneer over basalt flows and in some places basalt and alluvial material are interbedded (Gordon, 1961).

An example of how permeable and hydraulically connected the alluvium and basalt is to the SAG aquifer was demonstrated by the rise in static water level and change in water quality during operation of the Bluewater Mill. Recharge from seepage through the alluvium and basalt into the SAG aquifer was observed in less than a year after the beginning of operations in an existing well about one mile from a newly constructed Bluewater Mill waste water disposal pond. The SAG well was drilled in 1949 and the static water level showed a nearly constant depth of about 100 feet from the surface over seven years of monitoring (1949-1956). The waste water disposal pond was constructed and began operation in 1955. By the middle of 1956 when the pond was 30 to 40 acres in size, the static water level in the nearby SAG well had risen by about 10 feet because seepage from the disposal pond had recharged the local ground water. Changes in the chemical quality of the ground water more than the noticeable rise in the static water level clearly indicated that disposal pond water seepage down through the alluvium and basalt into the SAG aquifer was extensive in the late 1950s.

Ground water recharge in the SAG aquifer generally moves eastward or northeastward along the regional dip of the strata. Starting in 1944, irrigation wells constructed in the SAG aquifer began to withdraw significant quantities of water which caused spring discharge and ground-water levels to noticeably decline. The number of irrigation wells increased from 7 in 1945 to 23 in 1954, and ground water pumpage was estimated at about 14,000 acre feet during 1954 (Gordon, 1961). During the next 26 years, the use of ground water shifted from predominantly irrigation to industrial and municipal use.

The relationship of geologic structure and ground water occurrence is complex and difficult to locate in the Bluewater-Grants area (Gordon, 1961). The SAG aquifer outcrops along the southwest margin of the valley at an altitude of about 6,600 to 6,800 feet, and dips toward the north and northeast. Ground water in the SAG aquifer west of I-40 flows northeast because of the structural and topographic position of the unit. Fluctuations in water levels due to pumping and seasonal changes make it difficult to define where the ground water system changes from water table conditions to a confined system in the Bluewater-Grants area. Figure 4 presents the well locations and water level contour map from Gordon's 1961 report.

Numerous normal faults in the area also affect the occurrence and movement of ground water. Gordon notes that northward and northeastward-trending faults near the community of Bluewater and the Bluewater Mill may affect the movement of ground water considerably. This fault system is identified by Kelley (1963) as the Ambrosia Fault Zone, which extends for approximately 25 miles with the southern end located slightly south of the Bluewater Mill site (Figure 5). Kelley also identifies the San Mateo Fault Zone as a major structure along the axis of San Mateo Creek, which appears to extend beneath HMC. Large numbers of small east-west faults across the two fault zones are observed on the geologic maps, which are assumed to have an impact on the occurrence and movement of ground water in the area.

Because the seepage from the disposal ponds at the Bluewater Mill were excessive and the impact on ground water quality was significant, the company developed an injection well to dispose of decanted effluent (West, 1972). A deep injection well was constructed and operated beginning in 1960 that released mill waste water into the Yeso and Abo formations across an injection zone about 900-1400 feet deep. The injection well operated from 1960-1973 according to a 1975 EPA report. The actual number of years the injection well operated and the total amount of waste water disposed are unknown, but it is estimated that over 500 million gallons of mill effluent were injected. Table 2 describes the Anaconda Bluewater Mill tailings pond water chemical quality. Figure 6 is a geohydrologic map of the Grants area that illustrates the stratigraphic units; geologic structures; Bluewater Mill disposal well location; local well locations; and ground water surface elevation contours in the alluvium-basalt and SAG Aquifer.

4.1   1975 USEPA Reports (ORP/LV-75-4)

Selected summary and conclusions regarding the shallow and deep aquifers near two uranium mill sites from the 1975 EPA report, *Ground-Water Quality Impacts of Uranium Mining and Milling in the Grants Mineral Belt, New Mexico*, are provided here because they provide more background for the NMED investigation of the SAG Aquifer across the study area.

1. Ground water development from the San Andres Limestone aquifer is extensive in the Bluewater area.
2. Bluewater Mill seepage from tailings ponds and migration of wastes injected into deep bedrock formations are observed in the SAG aquifer and in the alluvium, both of which are potable aquifers.
3. Grants and Bluewater municipal water supplies have not been adversely affected by uranium mining and milling operations to date.
4. With the exception of the areas south and southwest of the United Nuclear-Homestake Partners mill (now known as the Homestake mill), widespread ground-water contamination from mining and milling was not observed in the study area (see Figure 7). Throughout the study area widespread contamination of ground water with radium was not observed despite concentrations of as much as 178 pCi/l in mine and mill effluents. Ra removal from ground water is probably due to the sorptive capacity of soils in the area. In the vicinity of the Bluewater Mill, radium and nitrate concentrations in the alluvial aquifer decline with distance from the tailings ponds, but neither parameter exceeds drinking water standards (see Figure 8).

5. Ground water in at least part of the shallow aquifer developed for domestic water supply downgradient from the United Nuclear-Homestake Partners mill is contaminated with selenium.

6. Company data show that seepage from the tailings pond at the Bluewater Mill averaged 48.3 million gallons for 1973 and 1974. Average volume injected for 1973-74 was 91.9 million gallons. Therefore, approximately one-third of the total effluent volume remaining after evaporation (over 100 million gallons) entered the shallow aquifer which is a source of potable and irrigation water in the Bluewater Valley. From 1960 through 1974, seepage alone introduced 0.41 curies of radium to the shallow potable aquifer. Adequate monitoring of the movement of seepage and the injected wastes was not undertaken.

7. There are indications that waste injected into the Yeso Formation at the Bluewater Mill was not confined to that unit as originally intended in 1960. Three nearby monitoring wells, completed in the overlying San Andres Limestone and/or Glorieta Sandstone, showed trends of increasing chloride and uranium concentrations with time. Positive correlations of water quality fluctuations with the volumes of waste injected are further indications of upward movement. The absence of monitoring wells in the injection zone was a major deficiency in the data collection program during operation.

8. The lowest observed radionuclide concentrations (background levels) in ground water are summarized as follows (entire Grants Mineral Belt):

^{226}Ra	range = 0.06 – 0.31 pCi/l	average = 0.16 pCi/l
^{210}Po	range = 0.27 – 0.57	average = 0.36
^{230}Th	range = 0.013 – 0.051	average = 0.028
^{232}Th	range = 0.010 – 0.024	average = 0.015
U (nat)	range = 14 – 68 pCi/l	average = 35 pCi/l
	(9 – 44 ug/l)	(22.75 ug/l)

9. ^{226}Ra in ground water is a good radiochemical indicator of waste water contamination from mines and mills. Due to the low maximum permissible concentration (5 pCi/l), it also provides a good means for evaluating health effects. Selenium and nitrate also indicate the presence of mill effluents in ground water. ^{210}Po, ^{230}Th and ^{232}Th concentrations in ground water fluctuate about background levels and are poor indicators of ground water contamination from uranium mining and milling activities.

10. Company sponsored ground water monitoring programs ranged from inadequate to nonexistent. Actual monitoring networks were deficient in that sampling points were usually poorly located or of inadequate depth and location relative to the hydrogeologic system and the introduction of contaminants thereto. Ground water sampling and monitoring programs at that time represented minimal efforts in terms of network design, implementation, and level of investment.

11. Off-site ground water sampling networks did not utilize wells specifically located and constructed for monitoring purposes. Reliance on existing domestic or livestock wells fell short of the overall monitoring objectives. Deficiencies of this type can allow contaminants to proceed unnoticed. On-site wells constructed specifically for monitoring were generally not completed to provide representative hydraulic and water quality data for the aquifer most likely to be affected.

12. Proven geophysical and geohydrologic techniques to formulate environmental monitoring networks were apparently not used. Such techniques can assist in specifying sampling frequencies and provide the basis for adjustment of monitoring and operational practices to mitigate adverse impacts on ground water.

13. With regard to the Bluewater Mill waste injection program, all available chemical and water level data for pre-injection and post-injection periods should be evaluated to ascertain if waste is migrating out of the Yeso Formation and into overlying potable aquifers. Of particular concern are ^{226}Ra and ^{230}Th because of their abundance in the injected fluid. Limited chemical data indicating migration of waste beyond the injection interval necessitate that thorough re-evaluation be made of the long term adequacy of this waste disposal method. Construction of additional monitoring wells in the Yeso Formation and the SAG is in order. Because of low maximum permissible concentration (MPC) values, this is particularly true if increasing concentrations of ^{226}Ra and possibly ^{210}Pb appeared in the aquifers above the injection zone.

4.2   National Uranium Resource Evaluation (NURE) Grants Special Study

The National Uranium Resource Evaluation program was initiated by the Atomic Energy Commission (AEC) in 1973 with a primary goal of identifying uranium resources in the United States. During October and November of 1979, Los Alamos Scientific Laboratory (LASL) conducted a detailed geochemical survey of the GMD within parts of the Albuquerque and Gallup 2° quadrangles. Totals of 3,569 sediment and 167 water samples were collected from 2,601 locations within this study area. Of these, 1,981 sediment and 74 water samples were collected within the Gallup quadrangle. At 183 locations (111 in the Gallup quadrangle), specially collected sediment samples were sieved into 5 different size fractions to investigate the mineralogical distribution of uranium in sediments. The detailed survey sediment samples were analyzed by LASL for uranium and up to 42 additional elements. Water samples were analyzed by LASL for uranium only. The analytical data were released as the LASL Grants Special Study GJBX-351(81) report.

Archive data from water samples collected and analyzed in 1979 was obtained from the USGS NURE website database for the Bluewater, Milan, and Dos Lomas 7.5 minute quadrangles. The sample location number, surface gamma reading, and U concentrations for the Bluewater-Grants area presented in Table 3.   Figure 9 presents the Google Earth map of the 1979 NURE sample locations and uranium concentrations in ground water in the Bluewater-Milan area. It is important to note the archive uranium concentrations are given in units of part per billion (ppb) which is equivalent to units of micrograms per liter (ug/l).

5.0   Hydrogeology of the San Mateo Creek Investigation Area

The NMED study area focused on the Ambrosia Lake mining sub-district, specifically targeting the area south of the New Mexico State Road 605-509 junction to south of HMC. The northeastern part of the study area toward the community of San Mateo is drained by SMC. The northern part of the study area toward Ambrosia Lake is drained by Arroyo del Puerto. The two drainages intersect in the vicinity of the state highway 605-509 junction, and the San Mateo Creek master drainage channel continues south where it becomes hard to recognize in the vicinity of HMC. Previous investigations that focused on the hydrogeology of the study area include Cooper and John, 1968; Brod, 1979, and Brod and Stone, 1981. The EPA reports in 1975 discussed in the following section, and NMEID reports in 1980 and 1986 describe results of shallow ground water and surface water sampling in the vicinity of and down gradient of uranium mills in the Ambrosia Lake area during the active days of mining and milling in the area.

The study area is located along the southern margin part of the San Juan basin where it is influenced by three regional elements: the Zuni Uplift on the south, the Chaco Slope on the west and north, and the Acoma Sag on the east. The Mount Taylor volcanic area is a major physiographic feature in the eastern part of the study area.   The general dip of bedrock units in the study area is toward the north and northeast. The displacement on the downthrown side of the San Mateo Fault fault system is estimated to be about 250 feet in the vicinity of the highway 605-509 junction (Cooper and John, 1968).

The geologic bedrock formations in the study area that are important water-bearing units and aquifers are primarily sedimentary in origin. From south to north across the study area Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary rocks are exposed at the surface. Ground water flow in the alluvium is generally southward, whereas flow in the bedrock aquifers is generally north and northeast. Quaternary alluvium occurs primarily along arroyos and major drainages such as SMC. In the study area the two major aquifer units consist of the Jurassic Morrison Formation (Westwater Canyon Member) and the Quaternary alluvium. Other aquifer units may include undifferentiated Triassic (Chinle Formation), undifferentiated Jurassic and Cretaceous Dakota Sandstone, Mancos Shale, and Mesa Verde Group (Point Lookout Sandstone and Menefee Formation). During the active period of uranium mining and milling, ground water was pumped from the ore-bearing Morrison Formation Westwater Canyon Member and discharged to both the Arroyo del Puerto and SMC. Water from the Morrison Formation was also used to supply the

mills in the Ambrosia Lake area. Mine discharge water created visible surface flow for several miles until it eventually infiltrated the alluvium. The alluvium also received seepage from uranium mill tailings waste discharge ponds.

5.1   Historical Water Quality Impacts in the San Mateo Creek Basin

The 1975 EPA report, *Ground-Water Quality Impacts of Uranium Mining and Milling in the Grants Mineral Belt, New Mexico*, describes results and interpretations of water quality sampling in the Arroyo del Puerto and the drainage junction with SMC. During the time of sampling the Kerr-McGee Mill (now known as the Rio Algom Ambrosia Lake Mill) and the United Nuclear Corporation Mill (now known as the Phillips Mill or the Ambrosia Lake Disposal Site) were operational. The Arroyo del Puerto received discharge from tailings pond seepage, ion exchange plants, and mine dewatering (Table 4). Water discharged to the Arroyo del Puerto was high in TDS, NH_4, Cl, NO_3+NO_2, and Ra. Discharge from ion exchange plants contained elevated levels of TDS, pH, trace metals (As, Ba, Se, Na, Cl, Ca, Mg, U, V, Zn), and radionuclides (gross alpha-beta and Ra). These discharges often exceeded the National Pollution Discharge Elimination System (NPDES) permit criteria for radium and uranium.

During the 1975 evaluation, stream stations were designated as sampling points downstream of U mining facilities to determine the effect of mine and mill discharges on surface water quality in the Arroyo del Puerto and SMC drainages (Table 5). There was no flow in these drainages up stream of the point where discharge water entered the stream channel. Some concentrations of radionuclides (Ra) and metals (Se and V) often exceeded the State of New Mexico Water Quality Standards for livestock watering that were prescribed at the time.

Discharge from a mine in Poison Canyon to a drainage that joined SMC contained elevated levels of TDS, trace metals, and radioactivity. Ground water affected by seepage from acid leach U mills like those in the Ambrosia Lake area was characterized by high concentrations of SO_4, Cl, NO_3, Fe, Al, and Mn (Longmire and Thomson, 1984). U mine effluents adversely affected surface chemistry and contaminated the shallow Alluvial aquifer with elevated concentrations of gross alpha activity, U, Mo, and Se (Gallaher and Cary, 1986). Earlier analysis of six natural surface water samples in the SMC area had an average TDS concentration of 180 mg/l predominantly in the form of Na, Ca, and HCO_3 ions (Gallaher and Cary, 1986). During this same time period, raw mine water had median TDS and SO_4 concentrations of 1,235 and 715 mg/l, respectively (10 samples). Treated mine water had average TDS and SO_4 concentrations of 1,440 (26 samples) and 655 mg/l, respectively (22 samples). It is assumed that raw mine water and treated mine water that was discharged to the Arroyo del Puerto infiltrated and recharged the Alluvial aquifer and possibly subcropping bedrock units.

5.2   National Uranium Resource Evaluation (NURE) Grants Special Study

The Grants Special Study was described above and the retrieval of archived water sample data for uranium concentrations was expanded to include more of the SMC area ground water sample locations. The Bluewater-Grants and San Mateo Creek area NURE water sample location number, surface gamma reading, and U concentrations were presented earlier in Table 3. Figure 10 presents the Google Earth map of the 1978-79 NURE sample locations and uranium concentrations in ground water in the Bluewater-Grants and San Mateo Creek areas. It is important to note the archive U concentrations are given in units of parts per billion which is equivalent to units of micrograms per liter.

The NURE water data for U in the Milan 7.5 minute quadrangle sample locations was evaluated for a range and average value without sample number 1081700 (69.72 ug/l) because it is assumed to be impacted. U values in water samples ranged from 0.59 ug/l to 8.55 ug/l, and averaged 3.11 ug/l. It is important to note that natural concentrations of U in ground water not impacted by U mining and milling operations were generally low (< 10 ug/l). The observation presented here does not substitute for a statistical, quantitative analysis of background U concentrations in ground water. It merely suggests that the concentrations of U at the lower end of the range of natural values are possibly less than 10 ug/l depending on location of the water sample and the hydrostratigraphic unit.

6.0 Sample Locations

6.1 Bluewater Mill SI Well Information

The sample designation, "BW-##," stands for "Bluewater" and the "sample number-location" (note that the sample prefix was documented as "BWSI" in the investigation). Generally speaking based on limited historical well construction record information, well owner recollection, and conversation with local drillers; the majority of the deep wells are completed in and draw water from the SAG hydrostratigraphic unit. Almost all of the surface completion structures for the wells do not contain an opening for a water level probe with the exception of the Bluewater Mill site monitoring wells. Five water level measurements were taken at the time of water sample collection from BW-23, BW-25, BW-26, BW-27, and BW-28. Table 6 presents well construction information for the Bluewater mill SI set of wells sampled in this investigation (NMED, 2009).

Table 6 suggests that the land surface drops about 100 feet in elevation from west to east until it reaches the area of well locations around HMC. From here the surface elevation rises toward the SMC area. Table 6 also suggests the group of 33 wells that were sampled is deeper at the margins of the study area, whereas in the middle of the study area the wells are shallower. The deeper wells likely draw water from multiple zones of variable lithology, which may be reflected in the sample chemical results. Sample number BW-07 is omitted from further analysis because the well went dry in late 2008 and preliminary interpretation suggests the well is completed in the Yeso Formation.

6.2 San Mateo Creek Well Information

The sample designation with the two letter abbreviation and number, "SMC-##," stands for "San Mateo Creek" and the "sample number-location. Well construction information describing the well depth; top and bottom of the screen interval; depth to the static water level (SWL); and which hydrostratigraphic unit(s) produces water for the well was not directly available for most wells sampled in the SMC investigation, and were inferred mostly from New Mexico Office of State Engineer records where possible. Twenty four of the 27 unique SMC sample locations were referenced in various documents with some amount of well construction information although some of it did not always match. Reasons for the construction information not to match at the same well location include: transcription errors, incorrect original information; incorrect field information; information too general; filling of the bottom of the well with sediment; and significant changes in SWL values over time. As a case in point to demonstrate the questionable reliability of well construction information, SMC-07 is from a well located in the northwest part of the study area above Ambrosia Lake, and the well depth is reported to be 800 or 1,200 feet deep (Table 7). The SWL is reported to be 744 feet deep. SMC-07 is reported to be from a well completed in the Jurassic Morrison Formation, Westwater Canyon Member (Jmw). Table 7 contains well construction information for the San Mateo Creek set of wells sampled in this investigation (NMED, 2010).

Sample SMC-01 was a duplicate from the previous Bluewater investigation at sample location BW-34, and is not included in the following hydrogeologic analysis. Samples SMC-03, -04, and -05 were collected at locations in the extreme southern part of the study area as follow-up to an earlier investigation, and they also are not included in the main interpretation of the ground water flow system in the target study area.

Samples SMC-08, -10, -11, -12, -13, and -14 are located in the same general area within the San Mateo Creek alluvial channel (see Figure 1). With the exception of SMC-08 the other five wells are designated to be completed in the Quaternary alluvial aquifer (Qal). Generally speaking and as a qualitative rule of thumb, Qal wells in this area are generally are less than 130 feet deep, averaging about 90 feet deep, and have a SWL of between 30-80 feet depending on location, with an average SWL of 38 feet. Most Qal wells were constructed in order to yield reliable water for agriculture and livestock supply. However, these wells may draw water from more than one hydrostratigraphic unit, which makes interpretation of hydrogeochemistry a challenge as samples may represent a mixture of different water sources. Moreover,

since the uranium mines are no longer dewatering and discharging water to the upper arroyos recharging the SMC alluvium, the SWLs in the Qal have likely dropped steadily since the late 1980s.

Another general rule of thumb for trying to determine the hydrostratigraphic units for wells sampled in this investigation is: the farther away from the alluvial channel the well is located, the more likely the well was constructed in a bedrock aquifer and not in the Qal unit. Some examples of this assumption include samples SMC-16, -17, -18, -21, -30, and -31. Wells in Table 7 that are indicated to be more than 150 feet deep are assumed to draw water from a bedrock unit. Additionally, if the well has little construction information, but the depth setting of the pump is given at more than 150-200 feet, then the well is assumed here to be a bedrock well. This logic and limited information does not identify which bedrock unit provides water to the well, but only helps qualitatively to differentiate between presumed Qal and bedrock well completions. Another important point to be mindful of is the possibility that even if a well location is determined and assumed to be a bedrock well and not a Qal well, it could still draw water from more than one hydrostratigraphic unit. Samples that contain a mixture of different water sources and different water chemistries are problematic for the interpretation of data for this investigation.

A key part of the methodology used in the interpretation of ground water geochemical data to help determine if sites have been impacted by legacy U mining and milling activities is to have samples from an area assumed to be largely representative of natural background water quality conditions. It is more difficult to distinguish mining water from background water because mining usually does not alter the water quality very much if at all, and chemically they may look the same for most parameters. The area of the Bluewater Mill investigation is assumed to be a ground water basin that has not been impacted to the same extent known or assumed for the area of the SMC investigation. However, the SAG Aquifer in the Bluewater area has probably received recharge from a variety of sources including precipitation, irrigation, agriculture, septic systems, historic mill operations water, and hydrostratigraphic unit interconnections. Aside from the possible sources of variable water quality recharging the aquifer, the SAG Aquifer is considered a reliable, valuable supply of potable ground water. The geochemical data from sample locations in the Bluewater area provide a basis for comparison of the data from the SMC sample locations. Figure 3 presented a map of all the ground water sample locations in the San Mateo Creek Basin.

7.0   Bluewater (BW) Ground Water Sample Results

In August and September, 2008 NMED collected 33 unique ground water samples from wells assumed to be completed in the SAG Aquifer in a generalized transect from west to east across the Bluewater-Grants area (Figure 2). Figure 11 presents the 33 ground water sample locations in the Bluewater investigation area. Table 8 describes: the sample number; field parameters; individual and average chemical values; and isotopic results for the Bluewater set of ground water samples.

Analytical errors are partly within the control of the chemist, type of analytical method used, and the type of instrument used to provide the measurement of the analyte. Generally speaking, water with a TDS concentration between 250-1,000 mg/l should result in a cation-anion balance of +/- 10%. Water having a TDS concentration greater 1,000 mg/l tends to have large concentrations of a few ions, and a test of the cation-ion balance does not adequately evaluate the accuracy of the lower concentration ions (Hem, 1985). Another procedure for checking analytical accuracy is to compare the determined and calculated values for TDS. The two values should agree within a few milligrams or tens of milligrams per liter unless the water is of a unique chemical composition (Hem, 1986).

There are four samples from the Bluewater Mill site deep monitoring well network included in the set of 33 samples (BW-25, BW-26, BW-27, and BW-28). These four samples are inferred to represent locations where the SAG Aquifer is contaminated by legacy uranium milling operation waste water releases because: 1) the wells for these samples are located on the mill site property where ground water contamination is already known to exist; 2) the water sample field pH values are not near neutral (7.0)

and are either relatively acidic (5-6) or alkaline (10); 3) the TDS concentrations are significantly elevated compared to off site ground water TDS concentrations; 4) the HCO_3 concentrations are at or much less than 100 mg/l due to the presumed buffering reaction with acidic mill waste water; and 5) several metal concentrations are distinctly elevated when compared to other metal concentrations in off site water samples (e.g. Cl, Fe, and Mn). Therefore, the inclusion of chemical values from the Bluewater Mill site monitoring well samples may skew the calculation of average values for some major ions. When average values from the four samples from the Bluewater Mill site deep monitoring wells are omitted from the calculation of average major ion concentrations, average Mg and K concentrations decrease by 0.1% (48.0 and 5.6 mg/l, respectively); average Ca concentration decreases by 0.9 % (169 to 163 mg/l); average Na concentration decreases by 7 % (149 to 129 mg/l); average Cl concentration decreases by 42% (179 to 73 mg/l); average SO4 concentration increases by 2.6% (420 to 443 mg/l); average HCO_3 concentration increases by 2% (278 to 291 mg/l); and average TDS concentration decreases by 5% (1,208 to 1,083 mg/l). The average lab pH value of 7.31 is for all 33 samples, while the average pH value for the set of 29 samples is 7.27—a decrease of 0.3%.

Average concentration values for remaining minor constituents and trace metal (generally less than 1.0 mg/l) in the set of 33 samples does not change significantly or at all when values from the four Bluewater Mill site wells are omitted from analysis. Many of the chemical values tested below the laboratory detection limit such that an actual measured value was not reported. When the majority of samples reported chemical values below the reporting limit, the reporting limit is listed in Table 8 as the average value for the parameter. For example, trace metals Ag, Al, Be, Cd, Co, Cr, Sb, and Tl reported all 33 sample values less than the reporting limit. Nine trace metal concentrations in a significant number of samples from this investigation were reported as less than the reporting limits: As = 16; Cr = 31; Cu = 32; Fe = 25; Hg = 20; Mn = 24; Mo = 25; Ni = 32; and Pb = 32. The large number of trace elements with reported values of less than the reporting limits results in actual measured values not available for geochemical analysis and interpretation. It is assumed based on the chemical results from this sampling event that many trace metals are not present in ground water at levels that can be measured using standard laboratory methods, or they are entirely absent in the ground water. For some specific calculations and graphical plots in this report, a value that is 50% of the reporting limit is used when sample chemical results are reported as less than reporting limits.

Fluoride data (average: 0.37 mg/l) are omitted from analysis because it does not appear to provide any indication of contamination compared to background. The NO_3+NO_2 data (average: 3.05 mg/l) were qualitatively analyzed by viewing the spatial variation and simple contouring of values across sample locations. Legacy releases of NO_3+NO_2 from the Bluewater Mill site are assumed to have dropped to levels that are unremarkable and/or similar to or masked by contributions from sources not related to U milling operations. The NO_3+NO_2 data is omitted from further analysis because agriculture and septic systems are also possible sources to ground water in the study area. Radiochemical and isotopic results will be analyzed and discussed in later sections. A limited evaluation of the geochemical data and interpretation of the ground water flow system has been documented in this report using major ions pH, TDS, and the five trace elements As, Ba, Se, Zn, and U.

The TDS of the 33 water samples ranged from 422 mg/l (BW-22) to 4,720 mg/l (BW-26), and averaged 1,083 mg/l for the group of 29 wells without the four Mill site samples. Based on the range and average TDS values, the ground water is simply classified as fresh to brackish water (Freeze and Cherry, 1979).

7.1   BW Spatial Changes in Chemistry

A brief mention of some basic concepts about the ionic evolution and tendency for TDS to increase along the ground water flow path is warranted to establish the rationale for inferences for the flow history of the ground water (Freeze and Cherry, 1979). As ground water moves along a flow path, the concentrations of TDS and major ions normally increase. Cherbotarev (1955) concluded that ground water tends to evolve by following the regional changes in dominant anion species:

Travel along flow path ———————→

HCO_3 ——→ $HCO_3 + SO_4$ ———→ $SO_4 + HCO_3$ ———————→

$SO_4 + Cl$ ———→ $Cl + SO_4$ ———→ Cl

Increasing age ———————→
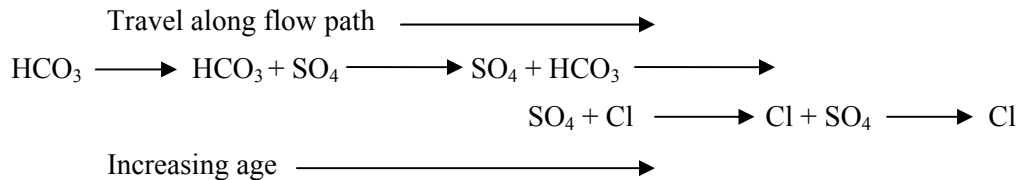
These changes generally occur as water moves from shallow (upper) zones of flushing (and recharge) through intermediate zones into lower (deeper) zones where the flow becomes more sluggish and the age of the water is older (Freeze and Cherry, 1979). Generally speaking, water moves through well-leached rocks in the upper zone and its chemistry is characterized by high HCO_3 concentration and low TDS (Domenico, 1972). Water in the intermediate zone has less active ground water circulation, by which TDS increases and SO_4 becomes the dominant anion. Water in the lower zone has very sluggish ground water flow, by which it acquires very high TDS concentrations, and Cl becomes the dominant anion. Generally, the most important cation exchange reaction along a ground water flow path occurs as Na is exchanged for Ca and the water becomes more saline the longer it has been moving along the flow path.

The chemical evolution of ground water in carbonate terrain (e.g. the San Andres limestone) is characterized by HCO_3 as the dominant anion and SO_4 as the second most dominant; Ca and Mg are dominant cations (Freeze and Cherry, 1979). Typically, the water has a pH between 7.0 and 8.0. The water in carbonate terrain generally follows an open-system dissolution model (water table condition) where water infiltrates the soil zone, carbon dioxide (CO_2) dissolves into the water, the water encounters carbonate minerals and the dissolution of calcite occurs according to the reaction:

$$CaCO_3 \text{ (calcite)} + H_2CO_3 \text{ (carbonic acid)} \longrightarrow Ca \text{ (cation)} + 2HCO_3 \text{ (bicarbonate anion)}$$

Ground water movement through sedimentary terrain that contains evaporite minerals typically involves the dissolution of gypsum according to the reaction:

$$CaSO_4 * 2H_2O \text{ (gypsum)} \longrightarrow Ca \text{ (cation)} + SO_4 \text{ (anion)} + 2H_2O$$

Major ion and TDS concentrations were plotted for sample locations along the assumed ground water flow path from west to east in Figure 12. The four samples from the Bluewater Mill site monitor wells are omitted from Figure 12 because they are contaminated by U milling waste water releases, which skews the "y" axis scale such that ion levels in the rest of the sample group are difficult to distinguish. Figure 12 indicates the major ion concentrations are highest for the anions of SO_4 and HCO_3, and the cations of Na and Ca. The levels of SO_4, HCO_3 and Na increase from west to east along the ground water flow path. The change in TDS concentration spatially along the ground water flow path is suggested to represent the overall variation in water quality across the study area. The TDS concentration ranges from about 700 to 1,300 mg/l in the west area around the Bluewater townsite, then drops to about 800 mg/l south of the Bluewater townsite. At sample location BW-17 the TDS concentration is 510 mg/l, which suggests the well at this location may receive fresh water recharge from the area highlands southwest of Interstate-40. Moving northeast from BW-17, the TDS increases to about 1,000 to 1,200 mg/l at sample locations BW-34 and BW-18, respectively, which are the two wells closest to the southern boundary of the Bluewater Mill site. Sample BW-18 appears to be located along north-south trending faults of the Ambrosia Fault Zone (Figures 4 and 5). Sample BW-34 may also be in a location influenced by faults.

Continuing south and east away from the BW-34 and BW-18 sample locations, TDS concentrations decrease to around 800 mg/l and thereafter to the lowest TDS concentration of 422 mg/l at sample location BW-22. Sample location BW-22 may also receive fresh water recharge similar to sample BW-17. Moving east from sample BW-22, the TDS concentration increases to 732 mg/l at sample BW-21 and then to 1,230 mg/l at sample BW-23. Samples BW-23, BW-04, BW-03, and BW-02 are generally located along a north-south line. Samples BW-04, BW-03, and BW-02 appear to have relatively similar ion concentrations and a TDS around 1,000 mg/l. Moving northeast toward sample locations BW-33, BW-

30, and BW-29, the TDS concentrations are 1,660 mg/l, 2,200 mg/l, and 1,840 mg/l, respectively. The wells at these three sample locations have documented completions in the SAG Aquifer, and are the deepest wells in the study area as shown in Figure 12 (800 to 1,000 feet deep). Samples BW-32 and BW-35 have TDS concentrations of 972 and 1,010 mg/l, respectively. Samples BW-29, BW-30, BW-32, BW-33, and BW-35 appear to be located along and influenced by the San Mateo Fault Zone as suggested in Figure 5.

7.2   BW Stiff Diagrams

Figure 13 is a Stiff diagram plot of major ion concentrations in milliequivalents per liter (meq/l) for each of the 33 sample locations. Stiff diagrams facilitate more rapid comparison of distinctive graphical shapes and individual chemical analyses by visual recognition (Freeze and Cherry, 1979; Stiff, 1951). Sample BW-07 is unique in shape from all other samples because of the high concentration of Ca and Na cations and the dominant SO_4 anion. As described earlier sample BW-07 is interpreted to be a well completed in the Yeso Formation and after sampling the well went dry. The Stiff diagrams for the Bluewater Mill site monitoring wells are distinctly different in shape because they are contaminated. Sample BW-25 is reported to be a background well for long-term DOE Site monitoring; however, the Stiff diagram is unique from the other sample Stiff diagrams around and immediately downgradient of the Bluewater townsite, which are assumed to represent upgradient background geochemistry. If sample BW-25 were representative of background water quality, then it would have more Ca than Na as the major cation. Ground water in carbonate units such as the San Andres limestone have the Ca ion as the most concentrated cation over other cations (Mg, Na, and K) because of calcite dissolution ($CaCO_3 + H_2O = Ca + HCO_3$). BW-25 also has a field pH of 10.21, whereas the field pH of ground water in wells sampled around the Bluewater townsite is approximately 6.7 to 7.0. It is possible that the well for sample BW-25 is impacted by the carbonate leach operation (high pH) at the Bluewater Mill that was operated before it was replaced by the acid leach system (low pH). The cation-anion balance error for BW-25 is 30.48% indicating the laboratory did not perform an accurate analysis of the major ions within customarily acceptable limits (10% or less).

Figure 13 indicates the other Bluewater Mill site monitoring wells have distinct Stiff diagrams that are unlike the other samples. Sample BW-26 shows a Stiff diagram with high values of Na and Cl and no HCO_3. The field pH of sample BW-26 is the most acidic of all 33 samples (5.40). It is likely the natural bicarbonate buffering capacity at the BW-26 well location has been consumed by high acidity water perhaps from the legacy acid leach processes, including the waste water disposal well operation, tailings evaporation ponds and the remaining tailings impoundment. Sample BW-26 has a cation-anion balance error of 21.86% indicating inaccurate laboratory analysis of the major ions beyond customarily-acceptable limits. Sample BW-27 and BW-28 are also unique in the shape of their respective Stiff diagrams compared to the other samples. The difference in field pH between samples BW-27 and BW-28 (6.48 and 8.66, respectively) indicates another aspect of variability in the local water quality that is complex and possibly due to a combination of contamination and faults that influence the geochemistry, occurrence and movement of ground water.

The majority of Stiff diagrams for most of the other water samples resemble small rectangular-shaped polygons that have a "nose" along the Ca axis and a "tail" along the SO_4 axis. For example, sample BW-06, BW-17 and BW-22 Stiff diagrams are nearly identical. Samples BW-17 and BW-22 appear to indicate low TDS water that has not been in the ground water system as long as BW-06 for exchange of Na for Ca, as indicated by the larger size of the BW-06 Stiff diagram. The Stiff diagrams for samples BW-23, BW-04, BW-03, and BW-02 are almost identical indicating the SAG Aquifer water chemistry is very consistent at these locations.

The Stiff diagrams for samples BW-33, BW-30, and BW-29 are similar to each other, but distinct from other samples. Na becomes the dominant cation over Ca at these three locations and the Cl and SO_4 anions also increase. Samples BW-33, BW-30, and BW-29 appear to represent ground water that is more evolved along the flow path by exchanging Na for Ca, and Cl and SO_4 for HCO_3.

The Stiff diagram for sample BW-32 is distinct and unique from all other samples because of the dominant Na cation and SO_4 anion. Sample BW-35 has a Stiff diagram similar to the majority of water samples in the study area. Samples BW-32 and BW-35 have slightly alkaline field pH values (8.27 and 8.48, respectively), whereas samples BW-33, BW-30, and BW-28 have slightly acidic field pH values (6.86, 6.69, and 6.75, respectively). The two order of magnitude variation in field pH at these five locations is not easily explained. It is possible that features like well completion/depth, proximity to the San Mateo Fault Zone and HMC, and longer residence time for the evolution of ground water along the flow path from different sources influence the resulting water chemistry at these sample locations.

BW-32 is interesting because of the unique major ion chemistry and the geographic location of the well. BW-32 has the second highest concentration of Na (423 mg/l) in the sample set (average = 129 mg/l), which is exceeded only by the BW-27 sample Na concentration of 535 mg/l. The Ca concentration (15.2 mg/l) is much lower than the sample set average of 163 mg/l. SO_4 (555 mg/l vs. 443 mg/l average) and HCO_3 (315 mg/l vs. 291 mg/l average) are slightly above the sample set averages for these two major ions. Based on these chemical parameters and the unique shape of the Stiff diagram, BW-32 has a major ion chemistry signature different than most of the San Andres samples. BW-32 is possibly the farthest down gradient, eastern most sample location directly along the assumed San Andres ground water flow path before or just as it intersects with the SMC alluvial system. The nearest upgradient well along the direct flow path direction is BW-28, which is about 4 miles away.

7.3   BW Trilinear (Piper) Diagrams

Figure 14 is a trilinear (Piper) diagram of the water samples, which show the relative percentage of ions in meq/l. The trilinear diagrams are used to show differences and similarities between the major ion geochemistry of water samples, and to infer the assignment of a sample location to a specific hydrostratigraphic unit (Piper, 1944). Trilinear diagrams permit the cation and anion compositions of many samples to be represented in a single graph in which major groupings or trends can be recognized visually (Freeze and Cherry, 1979). They also provide a means to visually describe differences in major ion chemistry in a ground water flow system based on the hydrochemical facies or water-type. Figure 14 indicates the ground water samples from the SAG Aquifer represent a range of water-types. The SAG Aquifer ranges from a Ca-Mg-Na/HCO_3-SO_4 water-type to a Na/Cl water-type, although most samples were characterized as a Ca-Mg-Na/HCO_3-SO_4 water. Water samples from the Bluewater Mill Site monitoring wells (BW-25, BW-26, BW-27, and BW-28) plot separately from the main group of samples. Sample BW-25 is a Na/HCO_3-Cl water-type, sample BW-26 is a Ca/Cl water-type, and samples BW-27 and BW-28 are Na/SO_4-Cl water-types. BW-32 has cation composition similar to that of BW-25 (high Na), but has an anion composition similar to the majority of other samples from this investigation (moderate HCO_3 and SO_4). The range of water-types represented by these samples indicates the ground water has a very complex chemistry that is difficult to explain with natural geochemical processes over such a short distance between well locations.

In the early part of the Bluewater Mill operation (mid to late 1950s), ammonium nitrate (NH_4+NO_3) was used to extract U oxide that adsorbed on to resins from the leachate solution (West, 1972). Beginning around 1960, an acidic solution of sodium chloride (NaCl) was used to extract the U oxide precipitate from the resins. The decant was neutralized with lime to cause other impurities to precipitate but still leave U in solution. The impurities were filtered out and discharged to the tailings pond. The remaining solution was treated again to precipitate U oxide, with the remaining liquid sent to the tailings ponds. Later in the operational period, the water in the tailings ponds was injected into the Yeso Formation through the disposal well. Based on the elevated levels of Na, Cl, and SO_4 in the Mill site monitoring well samples and their respective positions in the trilinear diagram, the SAG aquifer beneath the Mill site has been substantially altered by waste water containing high concentrations of acidity and NaCl.

The majority of the samples from wells other than those on the Mill site plot in one large group of water-types, and trends are evident between sample locations along the west to east ground water flow path in the study area. From west to east across the study area, ground water evolves from a Ca-Mg/HCO_3-SO_4 water (at and down gradient of the Bluewater townsite) to a Ca-Mg-Na/HCO_3-SO_4 water (in the vicinity

of the HMC Mill site). The percentage of cations in the ground water changes along the flow path as Na cations become more dominant over cations of Ca and Mg. The percentage of anions changes along the flow path as SO_4 concentrations become more dominant over HCO_3 concentrations.

The trilinear diagrams presented by Baldwin and Rankin indicate the SAG Aquifer can have a range of water-types and TDS concentrations. Water from the SAG is typically a Ca/SO_4-HCO_3 type of water, and Na concentrations are small relative to Ca concentrations. Baldwin and Rankin used the observation of higher Na concentrations relative to Ca to distinguish whether the producing aquifer was the SAG or sandstone beds in the Chinle Formation.

With respect to this investigation and the information presented above, if caverns and sinkholes in karstic SAG Aquifer contained fill from a variety of Triassic sediments, it may be difficult to distinguish between SAG and Triassic ground water by analysis of major ion water chemistry. Some of the inferred evolution and observed change in ground water chemistry along the west to east flow path may be due to the change in lithologic composition within the SAG Aquifer where the karst system is well developed and filled with younger age sediments from the Triassic. The trilinear diagram evaluation suggests this complexity on a regional scale because some samples have the same water-type even though their geographic locations and positions along the flow path are very different.

7.4 BW Ion to Ion plots

Another method of evaluating the geochemical data was performed by constructing x-y plots of major ions concentrations in mg/l. Various concentration plots of Ca: Na; Na:Cl; Na: HCO_3; HCO_3:SO_4, Cl:SO_4, and Cl: NO_3+NO_2 were created and visually evaluated. These types of plots are used to show chemical similarities among samples using the relative proportions of select ions as an indicator of mixing or grouping based on a particular attribute of the aquifer chemistry or hydrogeologic terrain (Hem, 1985). Qualitatively speaking, this technique was performed to visually check for mixing of water from beneath the Bluewater Mill with water types down gradient and across the study area. In most of the plots the high concentrations of major ions such as Na and Cl in samples BW-25, BW-26, BW-27, and BW-28 skew the scale of the plot such that it compresses the remainder of the samples into tight groups. Therefore, except for a plot of HCO_3:SO_4, the four Bluewater Mill site samples were omitted because they plot at the far right and top of the graph at a noticeable distance from the trend line. For example, Figure 15 is an x-y plot of Cl:SO_4 (without Mill site samples) with a trend line added to show how the sample values plot relative to the line. In many of the plots, it is worth noting that sample BW-18 often plots in a position separate from and midway between the main group of samples and the sample groups from the Bluewater Mill site and the deep water supply wells at HMC (BW-29 and BW-30). BW-18 may be a deep well that is located along a north-trending fault, and pumpage at this location may draw some water from beneath the Bluewater Mill site. BW-32 and BW-33 plot above the trend line because they have a higher concentration of SO_4. As noted in sections above, the sparse data and natural variability of major ion water chemistry in the SAG Aquifer in the study area present a challenge to flow path analysis using standard hydrogeologic methods.

Other than for qualitative visual comparison, the evaluation of geochemical data using x-y plots did not reveal any new insightful information about the possibility of mixing of ground water from beneath the Bluewater Mill site with water at offsite well locations. It is possible that some degree of mixing of water from the Bluewater Mill site is represented by samples from offsite well locations.

7.5 Bluewater SI Select Trace Metal Results

As described above, dissolved concentrations of five trace elements As, Ba, Se, Zn, and U are used here to evaluate the geochemical data and to make interpretations about the ground water flow system. Concentrations of the five trace elements were plotted for sample locations along the assumed ground water flow path from west to east in Figure 16. Figure 16 includes the Bluewater Mill site monitoring wells samples to evaluate possible relationship between contaminant levels in the site ground water and in off site well water samples. A value of 50% of the reporting limit is used in Figure 16 for concentrations where the reported values are below reporting limits. Comparison of the trace metal results for samples

BW-32 and BW-33 is problematic because these two samples were analyzed by SLD, rather than through CLP. The reporting limits for trace metals are lower at SLD (<1 or <10 ug/l) than at CLP (<5 or <20 ug/l), except for Fe which was higher at SLD (<50 vs. < 25 ug/l at CLP).

Arsenic concentrations are generally unremarkable across the study area and 16 sample locations reported less than the detection limit. The average As concentration was less than 5 ug/l. The highest As concentration was BW-09 (11.5 ug/l). Arsenic is common in the tailings waste effluent that was disposed to the Anaconda mill disposal well (Table 2).

Barium is the second highest trace element concentration in ground water samples across the study area (22.4 ug/l average), and the levels are unremarkable. Seven samples reported less than the detection limit. Eight samples in the middle part of the study area (BW-15 through BW-21) averaged about 28 ug/l of Ba. The fairly common mineral, barium sulfate ($BaSO_4$) is likely to control the concentration of Ba in natural water (Hem, 1985). Durfor and Becker (1964) reported the median concentration of Ba in public water supplies was 43 ug/l.

Selinium concentrations range from 31 ug/l at BW-18 to less than detection at five sample locations. The average Se concentration is 9 ug/l. Well samples in the middle part of the study area had slightly higher Se concentrations and levels increased slightly from west to east. Se is a relatively rare element and concentrations are generally very low (1 to 2 ug/l) in most natural waters (Hem, 1985). The low-temperature geochemistry of Se with particular references to Fe and U was studied by Howard (1977). Se occurs in oxidizing solutions as selenite (SeO_3) or selenate (SeO_4) ionic species, but it is easily reduced to elemental and nearly insoluble Se. Se may form the mineral ferroselite ($FeSe_2$) in the presence of Fe, and may interact with or adsorb on ferric oxyhydroxides. Se minerals are associated with U sandstone ore deposits of the Western United States (Hem, 1985). Se was concentrated in the Bluewater Mill tailing waste water as indicated in Table 2.

Zinc concentrations are higher than the other trace element concentrations particularly for samples in the western part of the investigational area (BW-05, BW-07 and BW-24), at BW-34, and in the deep supply wells at HMC (BW-29 and BW-30). The highest Zn concentration of 392 ug/l was in sample BW-07, a well that is assumed to be completed in the Yeso Formation. Thirteen samples reported less than the detection limit. The average Zn concentration of 78.9 ug/l is more than expected for the ground water in the SAG Aquifer and not easily explained. Based on published literature studies, Zn concentrations are usually much less than 50 ug/l in surface water (Hem, 1985). It is possible that the elevated Zn levels are from the corrosion of well pipes and galvanized plumbing fixtures, but the corrosion would need to be significant to maintain such high levels over time. Pb-Zn deposits in carbonate rocks contain hundreds of mg/l Zn in water samples from the ore zone (Hem, 1985). Zn was concentrated in the Bluewater Mill tailings waste water that went to the disposal well (Table 2). According to published literature, solubility data for Zn carbonate and hydroxide suggest that water with 610 mg/l HCO_3 and a pH of 8.0 to 11.0 should contain less than 100 ug/l of Zn (Hem, 1972b). Zn complexes of carbonate, SO_4, and Cl are probably controlling the occurrence of Zn in ground water.

The only other noteworthy trace element results at wells not located on the Bluewater Mill or HMC sites are limited. BW-29 reported measurable Mn, Ni, and Pb (14.9, 54.3, and 3.6 ug/l, respectively). BW-32 reported measurable Mn and Mo (6 and 9 ug/l, respectively).

7.6   BW Dissolved Uranium Results

U has an average concentration of 11.5 ug/l across the study area (Figure 17). Sample location BW-34 has the highest U concentration at 53.3 ug/l, and the second highest sample concentration is BW-32 with a U concentration of 29 ug/l. BW-34 is from a well that is 275 feet deep, and BW-32 is from a well that is 864 feet deep. Table 3 and Figure 7 describe NURE sample number 1081738 which visually appears to coincide with the BW-32 sample location and U concentrations are similar. The gross alpha activity value for BW-32 is 29 pCi/l which is the same numerically as the U mass concentration of 29 ug/l. From a radiochemical rule of thumb for a given water sample, the gross alpha activity should be higher than or

not equal to the U mass concentration because the radioactivity should always be higher since it includes all radionuclides in the sample and not just U.

Figure 17 presents three sample groupings based on their general position across the investigational area. The most western group of 10 samples is located in the Bluewater townsite, with an average U concentrations of approximately 7.8 ug/l. The middle group of 11 samples averages approximately 12.7 ug/l of U, and 8.7 ug/l when sample BW-34 is omitted because it is so much higher than most of the samples. The eastern group of nine samples from around HMC averages approximately 12.9 ug/l of U. Sample BW-32 is from a deep well located upgradient of HMC so it is possible the U at this location is naturally occurring, or from a source at the Bluewater Mill site, or from the SMC alluvium that is in hydraulic connection with the SAG Aquifer in this area.

Uranium is generally present in dissolved concentrations between 10 to 100 ug/l in most natural water (Hem, 1985). Total concentrations of U are technically a mixture of solid particles suspended in a liquid and are not reliable indicators of the dissolved geochemistry of the metal ion in solution. Limestone and sandstone rocks typically contain U concentrations of 2 mg/kg (ppm) on average (Drever, 1982). Concentrations of U greater than 1.0 mg/l can occur naturally in water associated with U ore deposits, but it is not uncommon to find ground water with low U concentrations associated with U ore deposits. Uranium concentration in soil is typically about 3 micrograms per gram (ug/g), however, in areas like New Mexico, concentrations of U per gram of soil range between 0.1 to 5.1 ug/g (ATSDR, 1999). Geochemical conditions that favor mobility of the oxidized U^{6+} species occur in near-surface, unconfined aquifer environments that are open to the atmosphere and contain sparse organic matter (Zielinski et al., 1997). Optimal chemical conditions for dissolved U^{6+} species include measurable concentrations of dissolved oxygen and carbonate to help form stable compounds of uranyl carbonate (Langmuir, 1978). Uranyl complexes with major ions of HCO_3 and SO_4 may also contribute to the concentration of U^{6+} form (Hem, 1985).

The NURE data demonstrates that there is U in the ground water around and up gradient of the Bluewater Mill site. The issue of what is the natural level of U in ground water prior to mining and milling is complex. Quantitative determination of natural U concentrations is a challenge because there is a lack of historical information to compare to the current set of sample results. The earliest known descriptions of U concentrations in ground water samples were taken from the 1975 EPA report and the NURE program data presented earlier in Table 3 and Figure 7. These data indicate that naturally occurring levels of U in the study area are represented by a range or average value depending on variables such as well locations, well depths, aquifer unit, and local geology. EPA (1975) cites a range of 9-44 ug/l or an average of 22.7 for natural levels of U in the Grants Mineral Belt. The NURE data for U concentrations in water samples from the Bluewater and Milan 7.5' quadrangles suggest an average of 1.8 or 3.1 ug/l, respectively. NURE sample number 1081700 has a U concentration of 69.72 ug/l and the well is assumed to have been impacted by releases from HMC at the time the sample was collected. Sample 1081700 was removed from the calculation of an average value for the Milan quadrangle set of NURE samples. Another complicating factor is that the historical sampling data were probably collected from more than one aquifer unit so the range and average values could represent a mix of hydrostratigraphic units. This aspect also applies to the 2008 NMED sample data because the well completion information is sparse or not known, and the samples are assumed to be collected only from the SAG Aquifer. Our sample results from around the Bluewater townsite indicates U in the ground water up gradient of the Mill site.

Interestingly, the four Bluewater Mill site deep monitoring wells tested below the reporting limit for dissolved U (2 ug/l), in comparison to the majority of wells sampled in this study, in which dissolved uranium occurs in quantifiable concentrations. The ground water in the SAG Aquifer beneath the Mill site is geochemically complex and it is difficult to explain the lack of U in the water without more sampling and geochemical modeling. Uranium was concentrated in the Bluewater Mill tailings waste water that went to the disposal well (Table 2). Geochemical processes such as precipitation, adsorption, and oxidation-reduction influence the concentration of dissolved U at these sample locations. It is worth noting that three of the four monitoring wells at the Mill site (BW-25, -26, and -27) had a negative

oxidation-reduction potential (ORP) when field parameters were measured during purging and sample collection. A negative ORP value indicates the water is reducing and suggests the U ion could be present in the reduced oxidized form of U^{4+} which is less soluble than the U^{6+} form (Hem, 1985). A positive ORP value was measured at the time sample BW-28 was collected which suggests the ground water was more oxidizing at this location.

7.7   BW Radiochemistry Results

Sample radiochemical results are presented in Table 4 in activity units of picocuries per liter (pCi/l) for gross alpha, gross beta, ^{226}Ra, and ^{228}Ra. It is important to note that gross alpha and gross beta are screening values for the sum of all alpha- or beta-emitters in a water. The gross alpha measurement is subject to inaccuracies from the effect of counting errors, TDS, and particularly the assumptions of the $^{234}U:^{238}U$ equilibrium. All of the potential alpha- and beta-emitting radionuclides were not measured in the water samples.

The sample gross alpha and beta results were not subject to spatial analysis along the flow path. Gross alpha ranged from 0 to 29 pCi/l and the average was 6.8 pCi/l. Gross beta ranged from 0.4 to 18.7 pCi/l and the average was 7.9 pCi/l. The low values of gross alpha and beta activities in the water samples indicate the ground water is generally very low in radioactivity. Most of the gross alpha activity in the water samples is from the presence of U. U concentrations are measured in units of mass (ug/l), whereas the gross alpha is measured in units of activity, pCi/l. A rough approximation of the gross alpha activity from U in the water is found by multiplying the U concentration in ug/l by 0.65 to obtain an approximate value of U in pCi/l (i.e. U ug/l X 0.68 = U pCi/l). If the conversion of U in mass units to activity units plus the Ra activity does not closely approximate the gross alpha activity of the water sample, then it is likely either that there are other alpha-emitters that were not measured in the sample, or the gross alpha measurement was inaccurate.

The Ra concentrations in the water samples along the ground water flow path are presented in Figure 18. Only one sample had a concentration above 1.0 pCi/l, which was BW-26 with a concentration of 1.65 pCi/l. The average ^{226}Ra concentration was 0.20 pCi/l and the average ^{228}Ra concentration was approximately 0 because of the 15 non-detect values. There were five non-detect values for ^{226}Ra. The 2008 NMED sample Ra concentrations are similar in comparison to the range reported in EPA, 1975 (^{226}Ra activity range of 0.06-0.31 pCi/l; average ^{226}Ra value of 0.16 pCi/l). Only sample BW-26 was outside the range and average ^{226}Ra value of the 1975 EPA data. The 2008 sample Ra concentrations also appear very similar to the range of concentrations depicted in EPA, 1975. Figures 5 and 6 that show ^{226}Ra concentrations in wells near the Bluewater and HMC sites.

The low Ra values are not unusual since most natural waters have concentrations below 1.0 pCi/l (Hem, 1985). Ra is highly insoluble in water and extreme conditions of pH and TDS (high levels of SO_4 and Cl ions) are necessary to bring the element into solution and keep it in the dissolved state. Ra is an alkaline-earth metal and has a chemical behavior similar to Ba which is why BaCl was often used to precipitate Ra out of U mine and mill water before it was discharged.

As described in the conclusions from the EPA, 1975 report, elevated Ra is a reliable indicator of waste water contamination from U mining and milling operations. Unfortunately, as an indicator or tracer, Ra's usefulness is limited because the radionuclide quickly precipitates or is adsorbed out of solution. For this reason Ra would not be a reliable indicator of U mill waste water contamination occurrence at off site wells unless conditions are extremely favorable for mobilization across several miles.

7.8   BW Uranium Isotope Results

Natural U is comprised of a mixture of three isotopes (^{238}U, ^{235}U, and ^{234}U). Natural U in undisturbed crustal rock, including U ore, is comprised of 99.284% ^{238}U, 0.711% ^{235}U, and 0.005% ^{234}U by relative mass abundance (ATSDR, 1999). Combining these mass percentages with the unique half-life of each isotope to convert mass into units of radioactivity shows that undisturbed crustal rock and U ore contains 48.9 % ^{234}U, 2.25% ^{235}U, and 48.9% ^{238}U (Parrington et al., 1996). The relative isotopic alpha AR of ^{238}U

to ^{234}U is approximately 1.0 in a state of equilibrium (48.9/48.9 = 1.0) when the rate of decay of ^{234}U is equal to the rate of decay of the ^{238}U parent. U isotope series disequilibrium has been measured in water by applying the concept of the AR (Osmond and Cowart, 1976; Gilkeson and Cowart, 1987). U ore deposits that have not been subject to major oxidative leaching within the last million years approximate a closed system in radioactive equilibrium with an AR near 1.0 (Zielinski, et al., 1997). High-grade U ore deposits that have a more recent history of open-system alteration are a mixture of materials with an AR > 1.0 and AR < 1.0 (Cowart and Osmond, 1997). In a closed hydrogeologic-geochemical system, there has been no exchange or dissolution of water and analytes into or out of the ground water system. In a sense, a closed ground water system does not receive recharge from outside and it does not allow water to move out. An open system is generally open to the atmosphere and water and analytes are able to move freely into, through, and out of the system.

Application of the isotope geochemistry & radioactive equilibrium conceptual model, in an ideal, closed system, the isotopic ratios of U are in natural equilibrium when they were deposited. Thousands to millions of years later, the system could have opened, ground water moved through & preferentially leached (fractionated)-precipitated the U ore deposit more than once. Then it was mined, leached, released, transported, adsorbed-desorbed, sampled, & analyzed by a lab. In isotope geochemistry, one has to be mindful of initial assumptions and to use the data carefully.

Raffinate is the leftover solution or waste water at a U mill after the U in solution has been removed by precipitation to produce U oxide or U_3O_8 (yellowcake). Rapid, nearly complete initial dissolution of U from finely crushed ore by oxidizing acidic or alkaline reagent solutions should not cause isotopic fractionation of the U isotopes (Zielinski, et al., 1997). Further chemical processing of the leachate solution by solvent exchange, sorption, or precipitation to remove the remaining dissolved U also does not substantially fractionate the U isotopes. Thus, raffinate should retain the original U isotope composition of the U ore deposit (Zieslinski, et al., 1997).

Fractionation of the U isotope occurs at the mineral/water interface during prolonged, mild leaching of U by ground water under reducing conditions. The alpha-recoil displacement of a ^{234}U atom from its parent ^{238}U atom in the mineral crystal lattice may help position the ^{234}U so it is more susceptible to leaching by ground water (Osmond and Cowart, 1976). Most natural ground water has a ^{234}U:^{238}U AR of 1. 0 to 3.0, but values in excess of an AR of 10 have been reported (Kronfeld, 1974; Szabo, 1982; and Gilkeson and Cowart, 1987). Raffinate waste water from a U mill should act as a conservative tracer to forensically identify the source of U in ground water by the AR value approximately equal to 1.0. The raffinate AR in the waste water would not change from dilution with other ground water as long as the other water contained no dissolved U. If the raffinate water mixes with a second source of ground water containing dissolved U of a different AR, then the resulting AR value would result in a value intermediate of the two endpoints (Van Metre, et al., 1997).

For the purpose of this investigation, the combination of U isotopic measurement and U mass measurement were hypothesized to act as a tracer to forensically determine if a water sample contained an anthropogenic component from a U mining or milling facility. Measurement of the ^{234}U:^{238}U isotopic ratio can be used to distinguish between uncontaminated water and water tainted by U milling and leaching (Van Metre et al., 1997; Zielinski et al., 1997; and Tso, 2000). Several examples using this type of geochemical application are given. U isotopes were used to help distinguish between U derived from mining and milling operations in alluvium as opposed to downstream natural sources in ground water of the Puerco River Basin of Arizona-New Mexico (Van Metre et al., 1997). U isotopes were used to identify the contamination of near-surface ground water with isotopically distinct U mill waste raffinate near a mill in southwest central Colorado (Zielinski et al., 1997). U-contaminated ground water and solid rock interaction and U mass transfer between fluid and solid phases were examined using U series isotopic data at a former mill site in Tuba City, Arizona (Tso, 2000). Assessment of potential U emissions on environmental media from a U mill in southern Utah utilized U isotopes to help characterize the source of U in springs, wells, and surface water (Naftz, et al., 2009). The key point is the mill

raffinate water should have an U AR of about 1.0 which can be used to forensically distinguish it from other U ARs and possibly natural sources that should have U ARs greater than 1.0.

Figure 19 is from the paper by Zielinski et al. (1997) and it has important relevance to the interpretation of isotopic results for the Bluewater group of samples. U concentration and isotopic composition in the Alluvial aquifer were illustrated with a plot of AR relative to the reciprocal of U concentration. In this plot horizontal displacement of points to the right indicates a decrease in U concentration in the absence of isotopic changes. Decreases in the U concentration could result from initial dilution of concentrated raffinate with local ground water, by precipitation or by sorption. Apparent alignment of points along positive sloped mixing lines represent samples that are a mix of two solutions, one is the raffinate (AR near 1.0, high U) and the other is native alluvial ground water (AR = 1.3 to 1.5, low U). Most of the water samples plot along the middle mixing line. The rightmost and leftmost mixing lines are drawn through a few points that may be the results of processes other than mixing which may include precipitation, sorption, dilutions, and evaporative concentration. The intersection of the horizontal AR lines (AR = 1.3 and 1.5) with the leftmost and rightmost mixing lines approximates the background range of U concentrations in the Alluvial aquifer (6-70 ug/l). The measured background U concentration in the Alluvial aquifer ranged from 4-31 ug/l. The figure also illustrates the strong positive correlation between molybdenum (Mo) and U concentrations in the water samples as an indicator of the presence of U mill raffinate. Samples with an AR < 1.3 have Mo concentrations > or = 100 ug/l and are likely affected by raffinate. Samples with a Mo concentration of < 40 ug/l correlates with the U background concentration range measured in the Alluvial aquifer.

Figure 20 is a plot of the U concentration in ug/l and AR for the 11 samples from the Bluewater-Milan area. The reciprocal of the U concentration is not plotted because there are no samples of actual raffinate as in Figure 19 to provide one of the anchor points for a mixing line end member. One unfortunate weakness in this investigation is there are no samples of the Bluewater Mill raffinate and the U AR values to use for comparison so the data from Zielinski's paper is used as a surrogate. The U AR values in Zielinski's paper that chemically define mill raffinate waste water are between 0.98 and 1.06. In Figure 20 the AR range from the samples of raffinate in the Zielinksi paper is used to represent the possible AR range for the Bluewater Mill raffinate. **Bluewater sample U ARs that are between 1.0 and 2.0, and have a dissolved U mass concentration above 3X the BW sample set average concentration of approximately 12 ug/l (3X = 36 ug/l): are considered to possibly contain Mill raffinate waste water**.

As discussed above, the chemistry of the BW-25, -26, -27, and -28 samples is unusual for a number of reasons, particularly the absence of dissolved U. Samples BW-14 and BW-24 have an AR > 4 and a U concentration of between 10-11 ug/l. These samples may represent natural concentrations. In comparison samples BW-05, BW-15, and BW-23 have U concentrations between 10 and 12 μg/l, but AR values between 1.6 and 2.2. The U concentrations in these samples also may approximate natural concentrations for U; however, the low AR suggests the samples may possibly include some U from more than one source not necessarily anthropogenic.

Sample BW-32 has an AR of 2.08 and a U concentration of 29 ug/l. BW-32 is from an 864 foot deep well in the SAG Aquifer located north of HMC and inferred to be down-gradient of the Bluewater Mill. Sample BW-32 is interpreted to contain an anthropogenic component of unknown origin but possibly from the Bluewater Mill or from water in the SMC drainage. As discussed previously the hydraulic interconnections exist among the alluvium, Chinle Formation, and SAG Aquifer due to karst development, erosion, and deposition; therefore it is possible that ground water in the SMC drainage may be interacting with water at the BW-32 location. The NURE data presented earlier in Figure 7 shows U values of 26 and 28 ug/l for the BW-32 sample location. A georeference match of the NURE sample locations with the BW-32 location has not been performed although visually the sample locations appear to be the same. If the sample locations match and they are the same well location(s), then the U concentrations at this location appear to have been within the range of 26-29 ug/l since 1978-79.

Sample BW-34 has an AR of 1.10 which is very low and close to the upper range of the raffinate AR defined by Zielinski et al., 1997. BW-34 contains 53.3 ug/l of dissolved U which is above the natural ranges determined and suggested by this study, the 1975 EPA report, and the NURE sample data. BW-34 U mass concentration is also 3X the BW sample set average of 36 ug/l. **Based on the low U AR (1.10) and elevated U concentration (53 ug/l), BW-34 is interpreted to possibly represent ground water that is contaminated by raffinate waste water from the Bluewater Mill Site.** It is also important to remember that the BW-34 sample location is the closest well to the south side of the Mill site property boundary in the down gradient direction along the ground water flow path.

7.9 BW Stable Isotope Results

Eleven sample locations across the study area were selected for stable isotope sampling and analysis of oxygen, hydrogen, carbon, and sulfur. Stable isotopes are used to understand the source of a water, or the processes that affected a water since it first entered the hydrologic cycle (Drever, 1982). For example, major ion, trace element, and stable isotope chemistry was used to understand the flow patterns and factors that limit acid mine drainage in the Wasatch Range, Utah (Mayo et al., 1992). The chemical behavior of isotopes of the same element is nearly identical, but minor differences result because of the slight differences in mass, particularly for lighter elements. The differences in mass cause isotopic fractionation which offset the isotopic ratios in particular phases or locations because the history of processes between a source water and a resultant water are often different. Fractionation may be caused by processes such as solid-liquid reactions, oxidation-reduction, precipitation, and evaporation.

Stable isotope sampling locations were based on three general categories: assumed uncontaminated upgradient wells (northwest area); known contaminated wells on or near the mill sites; and assumed uncontaminated down gradient wells (southeast and eastern areas). Table 8 contains the results of isotopic measurements for deuterium (^{2}H), oxygen-18 (^{18}O), carbon-13 (^{13}C), and sulfur-34 (^{34}S).

7.9.1 BW Oxygen and Hydrogen Isotopes

The water molecule is comprised of hydrogen isotopes (^{2}H/^{1}H) and oxygen isotopes (^{18}O/^{16}O). The ratios of the isotopes are expressed in delta units (δ) as per mil (parts per thousand or o/oo) differences relative to an arbitrary standard known as *standard mean ocean water* (SMOW):

$$\delta \text{ o/oo} = [(R - R_{standard})/R_{standard}] \text{ X } 1000$$

where R and $R_{standard}$ are the isotope ratios, ^{2}H/^{1}H or ^{18}O/^{16}O, of the sample and the standard, respectively (Freeze and Cherry, 1979). The slight differences in vapor pressure and freezing points for the isotope forms give rise to differences in ^{18}O and ^{2}H (deuterium or D) concentrations in various parts of the hydrologic cycle. The isotopic content of a water will change as a result of evaporation, condensation, freezing, melting, chemical reactions, or biological processes. In the hydrologic cycle water evaporates from the oceans and is carried as a vapor to a land mass where it is condensed and falls as precipitation. As water moves farther inland, the process of evaporation, condensation, and precipitation is repeated many times. Since both the process is temperature dependent, the isotopic fractionation is temperature dependent (Freeze and Cherry, 1979). The isotopic content of precipitation is often complex and variable due to: 1) continental trends in average annual isotope composition (climate, altitude, topography, and latitude are factors); 2) seasonal variation at a given location; and 3) isotopic content of rain or snow during individual precipitation events are often variable and unpredictable.

The δ D and δ^{18}O values in precipitation and hence fresh waters generally plot close to a straight line $\delta D = 8 \delta^{18}O + 10$ (Craig, 1961). The position along this line (meteoric water line or MWL) of a particular rainfall depends primarily on the amount of precipitation that has occurred between the time the air mass left the ocean and the time of the particular rainfall event (Drever, 1982). When water evaporates from soil or open surface water bodies (lakes, rivers, ponds) under natural conditions, it becomes enriched in δD and δ^{18}O. The departure of δD and δ^{18}O concentrations from the MWL is a feature of the isotopes that can be used in a variety of hydrologic investigations. Sources of ground water and the history of the ground water can be interpreted using these isotopes.

Figure 21 is a stable isotope plot $\delta^{18}O$ vs. δD (o/oo) of 11 ground water samples from the Bluewater-Milan area, plotted with the Craig meteoric water line and the local meteoric water line for the Albuquerque area, New Mexico (Yapp, 1985; Plummer et al., 2003). The samples display a spatial variation in isotopic composition which suggests the ground water system is complex and not easily explained with the small number of samples. Delta ^{18}O values ranged from -8.99 o/oo to – 12.40 o/oo. Delta D values ranged from -71.8 o/oo to -93.3 o/oo. Average $\delta^{18}O$ and δD values were -10.04 o/oo and -77.66 o/oo, respectively. The ground water sample trend line slopes slightly toward the x axis and suggests that there may be an evaporation component in the sample isotopic composition. Waters subjected to excessive evaporation in closed basins and certain east African lakes and rivers have a unique isotopic composition that deviates from the MWL, and they plot along on a trajectory with a slope of about 5 (Craig, 1961). Sample BW-14 has the most negative (depleted) isotopic values suggesting it may receive precipitation recharge that contains less of the heavier isotopes compared to the rest of the samples. Mill site monitoring well samples BW-26, -27, and -28 plot at or below the more positive (enriched) end of the trend line suggesting these samples have been subjected to or mixed with evaporation water. The more enriched isotopic composition of these samples may represent waters that are from the U mill leaching circuit and tailings disposal ponds. The more positive isotopic values may also correspond to higher temperatures of precipitation formation that infiltrated and recharged ground water. Even though these three samples have isotopically similar compositions, their major ion water chemistries are very dissimilar. Mill site monitoring well sample BW-25 is the second most isotopically negative sample, and suggests it may contain a mix of isotopically negative and positive ground water.

The known contamination beneath the Bluewater Mill site exerts more influence on the resultant major ion geochemistry of the ground water than the dissolution of aquifer materials. If the hydrostratigraphic unit and dissolution of aquifer materials were the greater factors, then one would expect to see an overall higher TDS level in all well samples collected from throughout the Bluewater-Grants area. Instead the highest concentrations of TDS and major ions are found in samples from the Bluewater Mill site monitoring wells, and the samples collected from the Bluewater-Grants area had an average TDS of approximately 1,200 mg/l.

The remaining six ground water samples plot at or above the trend line for the sample set. Even though these samples have a similar stable isotopic composition of $\delta^{18}O$ between -9.5 and -10.5 o/oo, and δD between -80.0 and -70.0 o/oo, the major ion chemistry of the samples is variable. Interestingly, samples BW-23 and BW-24 have almost identical isotopic compositions and similar major ion chemistries, but the sample locations are about 7 miles apart in the study area. Sample BW-34 plots close to the three enriched Mill Site well samples and suggests it may contain water from the same source (raffinate waste water). BW-34 has the highest uranium concentration in the sample set of 53.3 ug/l. Sample BW-32 is from the deep well located north of HMC and has the second-highest uranium concentration of the sample set. It has an isotopic composition similar to the main group of samples, but a unique major ion chemistry.

7.9.2 BW Carbon Isotopes

One of the most important reactions in establishing the pH of a natural water system is the reaction of dissolved carbon dioxide with water (Hem, 1985). Concentrations of dissolved carbon dioxide (CO_2) and its dissolved species are reported as carbonic acid (H_2CO_3), bicarbonate (HCO_3), and carbonate (CO_3). Over most of the normal pH range of ground water (6-9), HCO_3 is the dominant species (Freeze and Cherry, 1979). A ground water is said to be buffered if its pH is not greatly altered by the addition of moderate quantities of acid or base solutions (Hem, 1985). Most natural waters are buffered to some extent by reactions that involve dissolved CO_2 species usually in the form of HCO_3.

The evolution of ground water in a carbonate terrain such as the SAG Aquifer system must consider the chemical interaction between water and carbonate minerals such as calcite ($CaCO_3$). The chemical evolution of ground water in a carbonate terrain is complex and constrained by open and closed CO_2 systems. Ground water will evolve to certain concentrations of pH and HCO_3 depending on interactive

chemical processes, reactions, travel time, and aquifer material composition. The stable isotopes of carbon, carbon-12 (^{12}C) and carbon-13 (^{13}C) are useful in understanding the geochemical evolution of ground water, the pH, and the buffering capacity. The isotopic ratio of $^{13}C/^{12}C$ is expressed as the delta notation, $\delta^{13}C$ in per mil (o/oo). Carbon-13 is fractionated in the manner similar to the isotopes of hydrogen and oxygen, and it can be a useful environmental indicator.

The isotopic composition of calcium carbonate precipitated from aqueous solutions is controlled by several factors including: 1) the $\delta^{13}C$ value of CO_2 gas in equilibrium with carbonate (CO_3) and bicarbonate (HCO_3) ions in solution; 2) the fractionation of C isotopes between CO_2 gas, the CO_3 and HCO_3 in solution, and solid $CaCO_3$; 3) the temperature of isotopic equilibrium; and 4) the pH and other chemical properties that have an effect on the abundance of CO_3 and HCO_3 ions in the system. The $\delta^{13}C$ values of carbonate rocks of marine origin of Cambrian to Tertiary age are virtually constant and close to zero (Faure, 1977). Freshwater carbonates are enriched in ^{12}C compared to marine carbonates and have more variable $\delta^{13}C$ values averaging about -4.93 +/- 2.75 o/oo (Keith and Weber, 1964). Calcites associated with organic material in the uranium deposits of the Wind River Formation (Lower Eocene) in Wyoming, have an average $\delta^{13}C$ value of -22.5 o/oo =/- 4.0 o/oo (Faure, 1977). The average crustal rock concentration of $\delta^{13}C$ is approximately -7.0 o/oo (Faure, 1977). Measurements of $\delta^{13}C$ values from ground water samples in the Middle Rio Grande Basin (MRGB) averaged -7.9 +/- 2.0 o/oo (Plummer et al., 2004). The $\delta^{13}C$ values in ground water of the MRGB appeared to reflect the ^{13}C from the source water, rather than the effects of geochemical reactions within the basin.

Using $\delta^{13}C$ it may be possible to determine if the principal contributor to C in ground water is from soil zone gas reactions or from dissolution of carbonate rocks. In most carbonate aquifers, soil zone organic activity and the dissolution of carbonate minerals each contribute about 50% of the aqueous carbon in solution (Mayo et al., 1992).

For the purpose of this investigation, 11 samples were collected and analyzed for $\delta^{13}C$. The HCO_3 content was too low in the four Bluewater Mill site monitoring well samples (BW-25, -26, -27, -28) so the precipitate volume was inadequate for analysis. The $\delta^{13}C$ values for the remaining samples ranged from -5.43 to -8.57 o/oo, and the average $\delta^{13}C$ value was -7.18 o/oo. Figure 22 presents the range of $\delta^{13}C$ values in various types of carbonate reservoirs and the $\delta^{13}C$ values for the Bluewater-Milan ground water samples for comparison (Eby, 2004). The range of $\delta^{13}C$ values for the Bluewater-Milan set of ground water samples is depicted in the area of red bar. The $\delta^{13}C$ content in the samples appears to be in the range expected for marine and freshwater carbonates and suggests that soil zone CO_2 contributes less than 50% of the aqueous carbon in the samples. Comparison of the Bluewater SI sample set $\delta^{13}C$ average (-7.18 o/oo) to the MRGB average $\delta^{13}C$ (-7.9 o/oo) is interesting, but the latter value represents a much larger flow system and the results of 250 samples compared to 11 samples. Similar to the MRGB $\delta^{13}C$ results, the geochemical reactions along the SAG Aquifer flow path appear not to extensively affect the ^{13}C content in the ground water. Interpretation of the $\delta^{13}C$ values in the Bluewater SI samples is extremely limited at this time, however, the results will be used for comparison and to assist in the interpretation of geochemical data from future water sampling and analysis in the SMC basin.

7.9.3 BW Sulfur Isotopes

Sulfur in the form of SO_4 ions in aqueous solutions enters the ocean primarily by the discharge of fresh water and originates as a weathering product of several mineral sources: 1) sulfide bearing sedimentary rocks; 2) evaporite rocks of marine origin; and 3) volcanic and primary igneous rocks (Faure, 1977). Igneous activity on a world wide basis has also influenced the rate and isotopic composition of S in the oceans. S is removed from ocean water by the formation of evaporite rocks, and by bacterial reduction of sulfate to sulfide followed by precipitation of pyrite and marcasite. The isotopic composition of S in the oceans has varied systematically throughout geologic time.

S isotopes are most widely used to understand the origin of solutions from which sulfide or sulfate minerals formed in the past, rather than to interpret modern waters (Drever, 1982). In the MRGB study, the isotopic composition of SO_4 in water is a function of the isotopic composition of the S source(s), and

the extent of sulfate reduction and/or sulfide oxidation within the ground water system (Plummer, et al., 2004). For the Bluewater SI samples were collected and analyzed for the $\delta^{34}S$ isotope in an attempt to understand the origin of S in SO_4 because the ground water in the Bluewater-Grants and SMC areas is known to contain elevated concentrations of SO_4. Discharge of mine water, seepage from acidic mill tailings disposal ponds, and dissolution of sulfide (H_2S) minerals such as pyrite (FeS_2) and sulfate minerals such as gypsum ($CaSO_4$) are potential sources of the $\delta^{34}S$ isotope in ground water. An earlier study of S isotopes in U deposits from the Grants and Laguna mining districts was conducted in order to help understand the role of anaerobically produced H_2S in the deposition of sandstone-type U deposits (Jensen, 1963). It is theorized that the $\delta^{34}S$ isotope composition of water samples collected in this investigation could be used to forensically trace the origin of SO_4, and help determine if the S in the ground water is naturally occurring and/or anthropogenic. The two primary sources of dissolved S in ground water should be from the dissolution of evaporites like gypsum and anhydrite, and from the oxidation of pyrite and other sulfide minerals (Mayo et al., 1992).

In a study of water samples of Fe-poor neutral mine drainage with elevated SO_4 (average < 60 mg/l), in the Wasatch Range, Utah, the mean $\delta^{34}S$ concentration was +5.5 o/oo which suggests dissolution of gypsum was primary source of S (Mayo et al., 1997). Comparatively, in water samples of Fe-poor neutral mine discharge with low SO_4 (average < 30 mg/l), the mean $\delta^{34}S$ concentration was -0.5 o/oo. A single sample of acid mine drainage had a $\delta^{34}S$ value of -0.2 o/oo and a SO_4 concentration between 30 and 60 mg/l.

Measurement of the $\delta^{34}S$ isotope in 152 samples of ground water from throughout the MRGB averaged +0.5 +/- 1.3 o/oo, and spanned a range of 43 o/oo from -23.0 to +19.7 o/oo (Plummer, et al., 2004). The isotopic composition of S in the MRGB seemed to reflect several sources of S including: oxidation of S minerals (depleted $\delta^{34}S$); precipitation ($\delta^{34}S$ < 4 o/oo); and Permian evaporites ($\delta^{34}S$ > 4 o/oo). Interestingly, dissolved SO_4 in water from seven wells completed in the Permian SAG from an area 50 miles from the southwestern margin of the MRGB had an average $\delta^{34}S$ of +11.8 +/- 0.6 o/oo (Plummer, L.N. and Anderholm, S.K., U.S. Geological Survey, unpublished data, 1987).

Eleven samples of ground water were collected and analyzed for the $\delta^{34}S$ concentration in the Bluewater Mill SI. Figure 23 presents the plot of SO_4 in mg/l compared to $\delta^{34}S$ concentration (o/oo) for these ground water samples. Two water samples (BW-25 and BW-28) contained such low SO_4 concentrations that the sample did not yield an adequate amount of precipitate for isotopic analysis. The remaining nine samples had a $\delta^{34}S$ concentration that ranged from -13.61 o/oo to +14.26 o/oo. Without the only negative value in the set of nine samples (BW-32), the average $\delta^{34}S$ concentration in the eight positive samples was +9.36 o/oo. Three of the water samples plot close together (BW-05, -14, and -24), and are from wells in the Bluewater community located near each other. BW-32 plots separately from the majority of samples because it has a unique, negative $\delta^{34}S$ concentration. BW-32 is from a well that is located within the SMC alluvial drainage. The geochemistry at this sample location may reflect more of the SMC basin ground water chemistry than the Bluewater area chemistry.

Figure 24 presents the comparison of biogenic and hydrothermal $\delta^{34}S$ sulfur isotope values from various uranium ore deposits in the western United States and Grants Mineral Belt, and the $\delta^{34}S$ values for the Bluewater-Milan ground water samples (after Jensen, 1963). For comparison the range of $\delta^{34}S$ values for the Bluewater-Milan ground water samples are shown in the red area and the negative $\delta^{34}S$ value of sample BW-32 is shown as the dashed blue line. Sample BW-32 with a negative $\delta^{34}S$ value of -13.61 o/oo is similar to the $\delta^{34}S$ values of biogenic origin presented in Figure 24, whereas, the remaining samples have positive $\delta^{34}S$ values. The water samples with a positive $\delta^{34}S$ value are suggested to have a marine carbonate rock as the source of S, possibly the SAG limestone Aquifer (enriched in $\delta^{34}S$). Sample BW-32 with a negative $\delta^{34}S$ value is suggested to have a biogenic origin source rock that contained S enriched in ^{32}S and depleted in ^{34}S.

7.10   Bluewater Conclusions and Recommendations for Future Work

Historical data indicates there have been releases of contaminated waste water from the Bluewater and HMC Mill tailings disposal ponds. The releases documented impacted the shallow ground water units on and around both Mill sites and for the Bluewater Mill at least the upper part of the SAG Aquifer. The current extent and character of the impact to the ground water system from the Bluewater Mill Site tailings pond seepage is unknown. Additionally no evaluation of impacts to the Yeso and Abo Formations from historical operation of the Bluewater Mill injection well has been performed.

An updated and more sophisticated evaluation of the ground water system at and down gradient of the Bluewater Mill Site is necessary. This current SI has attempted to perform a baseline study of ground water chemical conditions using sophisticated geochemical parameters that had not been applied before throughout the well locations sampled in the study area. A total of 33 samples were collected and analyzed. Although the well locations were sampled and tested for a long suite of geochemical and basic radiochemical parameters, only a few wells were tested for isotope concentrations of hydrogen, oxygen, uranium, carbon, and sulfur. Future investigations should expand the number of wells sampled and tested for their isotopic concentrations.

Data from earlier reports describe the complex geologic history of the SAG Aquifer, and how the erosional surface and karst topography were developed and filled with materials from overlying strata. The degree of interconnection between the deep aquifer system and the shallow system is unknown. Hydrogeochemically, the sample major ion and trace element ion concentrations are so variable across the Bluewater Basin, it makes interpretation of chemical changes along the assumed flow path difficult to understand and interpret. The chemical variability also makes it a challenge to categorize and identify which wells are completed in specific hydrostratigraphic units by the hydrochemical data. The lack of current and detailed structural data is an additional hindrance to this effort.

One of the glaring weaknesses in this investigation is the lack of properly positioned and constructed monitoring wells designed to intercept possible contaminated water from the Bluewater Mill Site along the ground water flow path. The ground water flow path presented on maps used in this investigation was developed on data from the 1950s and 1960s. Since that period of time ground water use has changed throughout the Bluewater Basin. Current patterns of ground water usage and the resultant changes in the water surface elevation have been inadequately monitored and evaluated. It is suspected that some areas draw down the water surface more than other areas due to the presence of higher yield municipal, industrial, and agricultural wells possibly located along faults and highly permeable karst features in the SAG Aquifer. Geochemically, it may be difficult to identify contamination from the Bluewater Mill Site at some of these locations because the dilution from high volume mixing and flow may mask the indication of a chemical change.

Information about the geologic structures was presented, and it is suggested that the Ambrosia and San Mateo Fault Zones exert a major influence on the occurrence and movement of ground water near the Bluewater Mill and HMC Sites. There appears to be some geochemical and hydrogeologic evidence that a north-south trending fault(s) in the vicinity of wells at the BW-34 and BW-18 locations could facilitate the flow of contaminated ground water from the Bluewater Mill Site. Some of the inorganic chemistry, trace metal, and isotopic data for the BW-34 sample, especially the ^{234}U: ^{238}U AR, indicates the ground water at this location is unique from the background range of chemical parameters. It is suggested that sample BW-34 contains an isotopic signature that is the fingerprint of U mill raffinate waste water from the Bluewater Mill Site. Interpretation of the chemical condition of water at the BW-34 location should be confirmed using the same set of geochemical parameters and particularly the ^{234}U: ^{238}U AR analysis. The U isotope concentration at the BW-34 and BW-32 wells should be measured using the more precise inductively coupled-mass spectrometer (ICP-MS) equipment and methodology that is available at the University of New Mexico (UNM), Department of Earth and Planetary Sciences. Other chemical analysis using isotopes of tritium (^{3}H), nitrogen ($^{15}N/^{14}N$), and the noble gases like He, Ne, Ar, Kr, and Xe may be helpful to understand the hydrochemistry and possible sources-contributions of potential contaminant releases in the area.

Sample BW-32 is interesting because of its unique geochemistry and geographic location with respect to the presumed flow path directions in the SAG and San Mateo alluvium. BW-32 has a unique major ion chemistry similar in composition to constituents in the Bluewater Mill site monitoring well samples. It also has the second highest uranium concentration in the offsite well locations which is presumed to be down gradient of the Bluewater Mill site in the SAG. BW-32 possibly is located along the San Mateo fault zone that could extend from the surface to deep into the SAG. If the fault zone extent is deep, it is possible that it could provide hydraulic communication between the alluvial aquifer system and the deeper bedrock aquifer system. Isotopically, the sulfur isotope composition of BW-32 was the only sample that was compositionally more like the $\delta^{34}S$ values reported by Jensen (1963) in Figure 24 and the comparison of biogenic and hydrothermal $\delta^{34}S$ sulfur isotope values from various uranium ore deposits.

An integrated approach of baseline data collection, geophysical techniques, and exploratory drilling should be considered for understanding the hydrogeology of the study area, and to guide the proper placement and construction of monitoring wells. Even though the focus of these CERCLA SI activities at this time is to check existing wells for evidence of contaminant releases from legacy uranium mill site facilities, the main goal of understanding these contaminant distributions is a significant challenge because the knowledge level of the hydrogeologic system is very generalized or unknown for such a large, complex area. Access to existing wells could provide for the manual measurement of the static and pumping water levels on a minimal quarterly basis. Some wells should be evaluated and considered for pressure transducers and water level logging equipment at background locations, near major geologic structures, and at sites where the ground water extraction rate is significant on an annual and/or seasonal basis. Geophysical tools could be employed to help determine the elevation of the water table surface and the occurrence of major geologic structures and hydrostratigraphy. Empowered by more geochemical sampling data, water level information, and geophysical results, the selection of locations for exploratory drilling and monitor well construction would be more informed. Monitoring wells could be constructed in a nested configuration to capture data in more than one zone and to save cost. Table 9 summarizes the data gaps and recommendations for future work in the Bluewater area, New Mexico.

8.0   San Mateo Creek (SMC) Ground Water Sample Results and Discussion

In late March – early April, 2009 NMED collected 33 water samples during the SMC SI. The sample designation, "SMC-##," stands for "San Mateo Creek", and the sample number-location. Five samples (two field duplicate, two field blank, and one equipment blank) were collected per NMED Quality Assurance/Quality Control procedures. Only 28 of the 33 samples collected were from unique well sample locations. Sample SMC-01 was a duplicate from the previous Bluewater SI at sample location BW-34, and is not included in the following hydrogeologic analysis. Sample SMC-39 did not have enough volume to fill the full set of bottles for a complete sample, and subsequently only tested for radiochemistry and stable isotopes. The analysis and interpretation of ground water quality is based on the results of the 27 unique well samples. As previously noted, well completion information for wells utilized in this SI are sparse, and were used in conjunction with observations detailed in Section 6.2 to assign possible completion intervals. Figure 25 presents the sample locations in the SMC SI area. Table 10 describes the sample number; field parameters; individual and average chemical values; and isotopic results for the SMC set of ground water samples.

The TDS of the 27 water samples in the SMC study area ranged from 254 mg/l (SMC-30) to 3,400 mg/l (SMC-09), and averaged 1,369 mg/l for the group of 27 well samples. Based on the range and average TDS values, the ground water is simply classified as fresh to brackish water (Freeze and Cherry, 1979). The ranges and average concentrations, respectively, for the seven major ions were: Ca = 2.83 to 567 mg/l, 176.5 mg/l; Mg = 0.08 to 88.5 mg/l, 40.6 mg/l; Na = 24.3 to 628 mg/l, 221.7 mg/l; K = 0.5 to 9.4 mg/l, 4.2 mg/l; Cl = 2.5 to 125 mg/l, 35.6 mg/l; SO4 = 12 to 2110 mg/l, 684 mg/l; and HCO3 = 10 to 359 mg/l, 203 mg/l. Concentrations of the minor ions F and NO3+NO2 ranged from less than 0.25 to 1.68 mg/l and 0.02 to 22.80 mg/l, respectively; and averaged 0.71 and 5.55 mg/l, respectively.

The field pH ranged from slightly acidic (< 7.0) to slightly alkaline (>7.0) and averaged 7.58. Sample SMC-10 had the lowest pH (6.83) and SMC-22 had the highest pH (9.29). Field measurements of the ORP were predominantly positive values that averaged 50. Field measurements of dissolved oxygen (DO) concentrations averaged approximately 2.0 mg/l. The ORP values and DO concentrations appear to indicate the ground water is oxidizing at most well locations. The field DO measurements of ORP in sample SMC-09 appear to be unreliable and were not used in calculating average values because the value of approximately 70 mg/l is above a level that is ordinary under natural conditions for an unconfined aquifer in an open system in contact with the atmosphere. It is likely that the DO value is the result of operator error in reading or transcribing the meter value to the sampling field data sheet. Since the DO value is suspect, the ORP value was considered suspect and also not used in the calculation of average values for these parameters. Omission of the SMC-09 parameter values for DO and ORP do not result in a significant change in the average values for the SMC sample set for these two parameters.

The Cl concentration level in the SMC set of samples is much lower than the Bluewater SI samples. The average Cl value in the Bluewater SI samples is 72.9 mg/l, whereas, in the SMC SI samples the average is 35.6 mg/l. The overall lower concentration of Cl in the SMC group is unexpected because carbonate rocks such as limestone have a higher average composition of the element Cl at 305 parts per million (ppm) compared to sandstone with an average composition of 15 ppm (Horn and Adams, 1968). One must remember that a carbonate limestone is formed in a seawater environment that has an average concentration of 19,000 mg/l of Cl (Goldberg, et al., 1971).

Samples SMC-20, -21, -22, -23, -26, and -30 had a cation-anion balance error of greater than 10%. Under optimum conditions, the analytical results for major ions in water should have an accuracy of between +/- 2% to +/- 10% (Hem, 1986). When the TDS analytical accuracy check described earlier in the beginning of the Bluewater SI sample results discussion is performed, only sample SMC-21 continued to result in an approximate +/-50% difference which is unacceptable for quality assurance. SMC-21 has a very high concentration of dissolved solids primarily Ca, Na, and SO_4.

Dissolved Fe concentrations ranged from less than the limit of detection in 19 samples (<25 ug/l) to a high of 2,740 ug/l in sample SMC-08. The high Fe concentrations in SMC-08 and SMC-31 may be from the corrosion of steel casing in the well. The arithmetic average dissolved Fe concentration was 188.7 ug/l, but this value is somewhat misleading because the calculation uses so many values that are half of the detection limit (12.5 ug/l) and the high dissolved Fe concentrations of SMC-08 and SMC-31 skew the average to a higher value. For comparison, the median dissolved Fe concentration is 86.9 ug/l. Qualitatively, Fe concentrations in ground water in the SMC area are observed to be very low (<25 ug/l) and substantially elevated levels of dissolved Fe are suspected to be from corrosion of steel casing used in construction of the well. There is inadequate information to determine if elevated Fe concentrations are due to discharges and releases from U mining and milling operations. It is important to remember that the concentration and form of Fe in water can significantly contribute to the ORP condition of the water and the resulting concentration of other metals such as uranium (Garrels and Christ, 1964). Iron oxyhydroxide surfaces have a substantial capacity to adsorb other metals which may affect their concentrations in the water (Hem, 1977). Microbiota or Fe and S-reducing bacteria are common in aqueous environments where a source of Fe and S are available to contribute to the oxidation of steel casing-pipe. A better understanding of the aqueous metal chemistry of a ground water system would include measurement of dissolved Fe and Fe-speciation concentrations, which then can be used as input data to support geochemical thermodynamic modeling of water sample results.

Concentrations of NO_3+NO_2 ranged from 0.02 mg/l to 22.80 mg/l and averaged 5.55 mg/l. Eight wells assumed to be completed in Qal were observed to have the highest set of NO_3+NO_2 concentrations in the SMC sample set (SMC-10, -11, -12, 13, -14, -26, -33, and -34). The average NO_3+NO_2 concentration in this set of alluvial samples was 9.47 mg/l. Concentrations of NO_3+NO_2 in inferred bedrock water samples were usually less 1.0 mg/l (10 samples), or concentrations were between 1-2 mg/l (4 samples). Four samples had a NO_3+NO_2 concentration between 2 and 6 mg/l. It appears that samples from the

alluvial aquifer are more elevated in NO_3+NO_2 concentrations than bedrock aquifer samples by a few to more than 10 mg/l. Bedrock water samples with less than 1-2 mg/l NO_3+NO_2 suggest natural water quality conditions, whereas, elevated levels suggest a possible anthropogenic component that could include U mining and milling operations.

Fluoride concentrations ranged from 0.29 to 1.68 mg/l and averaged 0.71 mg/l. Fluoride data are omitted from further analysis because it does not appear to provide any indication of contamination compared to background. From here on in this report, a limited evaluation of the geochemical data and interpretation of the ground water flow system are performed using major ions, pH, TDS, and select trace metals. Radiochemical and isotopic results are analyzed and discussed in later sections.

The remainder of minor constituents and trace metal average values (generally less than 1.0 mg/l) in the set of 27 samples tested below the laboratory detection limit such that an actual measured value was not reported. When the majority of samples reported chemical values below the reporting limit, the reporting limit is listed as the average value for the parameter (Table 10). When actual numerical values are required for graphical plotting of samples results, a concentration equal to 50% of the reporting limit is used.

8.1   SMC Spatial Changes in Chemistry

A brief mention of some basic concepts about the ionic evolution and tendency for TDS to increase along the ground water flow path is presented earlier in Section 7.1.

Evaluation of the major ion concentrations between sample locations along a general north to south direction within SMC was performed by determining an order of sample locations from top to bottom of the basin. This sample order was used as a basis to generate x-y plots of major ion concentrations to check the variability of sample results along the flow path. Plots were also broken down by presumed hydrostratigraphic units (Qal, Jmw, and other bedrock units) to check for the evolution of major ion concentrations along a presumed flow path within a given aquifer. Figure 26 and 27 are charts of the major ion and TDS concentrations in mg/l at sample locations in aquifer units along the assumed ground water flow path from north to south in the San Mateo Creek area. These figures indicate the concentrations are highest for the anions of SO_4 and HCO_3, and the cations of Na and Ca. The levels of SO_4, HCO_3 and Na increase generally from north to south along the presumed alluvial ground water flow path. The TDS generally increases from the upper reaches of the Arroyo del Puerto (northern part of study area), and from the upper reaches of San Mateo Creek (northeastern part of study area). The change in TDS concentration spatially along the ground water flow path is suggested to represent the overall variation in water quality across the study area. The possible relationship of these observed geochemical trends to impacts from legacy uranium sites cannot be established with any degree of certainty

The TDS concentration ranges from 534 to 3,320 mg/l in the northern area of the Arroyo del Puerto drainage, and has an average concentration of 1,265 mg/l (5 samples). The TDS concentration ranges from 254 to 3,310 mg/l in the eastern area of the upper part of SMC drainage, and has an average concentration of 920 mg/l (7 samples). The group of sample location sites at the southern end of the SMC study area (SMC-08, -09, -10, -11, -12, -13, and -14) have the highest concentrations of TDS in any subset of samples. Two of the highest TDS values are from samples SMC-09 and SMC-10 (3,400 and 3,380 mg/l, respectively). The average TDS concentration in this subset of seven samples is 2,340 mg/l. The overall average TDS for the SMC set of samples is 1,388 mg/l. The next highest subset of sample locations with TDS values in the 2,000 to 3,000 mg/l range are found in the highway 605-509 junction area with samples SMC-21 and SMC-24 (3,320 and 3,310 mg/l, respectively).

Below the confluence of Arroyo del Puerto and San Mateo Creek, the TDS concentration is markedly higher because the majority of wells sampled are assumed to be completed in the alluvial aquifer with the exception of SMC-22 (TDS = 506 mg/l) which is possibly from a well completed in undifferentiated Jurassic and/or Triassic Chinle Formations. SMC-09 is possibly from a well completed in the undifferentiated Jurassic/Triassic Chinle Formations located in an unnamed alluvial tributary east of the

SMC alluvial channel, and it is possible that the geochemisty of this well is influenced by alluvial ground water from the Lobo Canyon area.

The field pH ranges from 6.84 to 8.20 in the northwest part of the study area, and has an average value of 7.38. The field pH ranges from 6.84 to 8.10 in the northeast part of the study area, and has an average value of 7.30. In the lower part of the study area, pH in the alluvial wells ranges from 6.83 to 8.76, and has an average value of 7.53. SMC-22 has a pH of 9.29, which is the highest pH value in the SMC sample set and not easily explained because it appears to be a bedrock well location with water low in TDS.

The NO_3+NO_2 data were qualitatively analyzed by viewing the spatial variation and simple contouring of values across sample locations. Two areas of elevated NO_3+NO_2 concentrations were identified: the intersection of state highways 605 and 509 (SMC-21, -23, -24, -25, and -26), and the cluster of wells above HMC (SMC-09, -10, -12, and -13). Concentrations of NO_3+NO_2 from the Ambrosia Lake and SMC area U mill site operational releases are assumed now to have dropped to levels that may not be clearly indicative of U milling operations. The NO_3+NO_2 data is omitted from further analysis because agriculture and septic systems are also possible sources to ground water in the study area.

8.2   SMC SI Stiff Diagrams

Figure 28 is a Stiff diagram plot of major ion concentrations in milliequivalents per liter (meq/l) for each of the 27 sample locations. The Stiff diagrams for samples from wells completed in the alluvium are distinctly different in shape for samples from wells assumed to be completed in bedrock units. Stiff diagrams from alluvial wells are larger in size compared to bedrock well samples because they have elevated concentrations of dissolved ions (primarily Ca, Na and SO_4 ions). The Ca and Na cations form an apex on the left side of the axis and the SO_4 anion forms a long tail on the lower right side of the axis (e.g., SMC-10 and SMC-11). Bedrock well samples are noticeably different in shape (thinner) compared to alluvial samples because they have an overall lower dissolved ion concentration (e.g., SMC-20, -28, and -34). Stiff diagrams for the bedrock aquifer units indicate Na cations are more dominant over Ca, and HCO_3 concentrations are slightly higher even though SO_4 is still the dominant anion. Some Stiff diagrams (e.g., SMC-08, -12, -14, -17) have the shape of a skewed hour glass which suggests the water chemistry at these locations could represent a mixture of alluvial and bedrock water sources. The skewed hour glass shaped Stiff diagram may also indicate another distinct variation in the range of water chemistry in the alluvial aquifer since most of the sampling locations are assumed to be shallow completions.

8.3   SMC Trilinear Diagrams

As shown in Table 10 and indicated above, limited data are available by which to identify and distinguish aquifer units from dissolved major ion results. A better determination of hydrostratigraphy is important to this investigation in order to discern whether contaminant releases have occurred from legacy uranium sites. Using historical well data and the geochemical results shown in Table 10, NMED created trilinear plots in order to evaluate sample geochemical results for possible groupings as another possible method to distinguish hydrostratigraphic units. Several iterations of sample results were plotted in the trilinear diagrams based on assumed hydrostratigraphic unit, geographic area, and range of TDS concentration. Figure 29 is a trilinear diagram of the relative percent of major ion concentrations in milliequivalent per liter (% meq/l) for ground water samples from the alluvial aquifer in the San Mateo Creek area. Figure 30 is a trilinear diagram of the relative percent of major ion concentrations in meq/l for ground water samples from the Jurassic Morrison Formation (Westwater Canyon Member) in the San Mateo Creek area.

The trilinear diagrams (Piper, 1944) are used to highlight differences and similarities between the major ion geochemistry of water samples, and to infer the assignment of a sample location to a specific hydrostratigraphic unit. The left triangle displays an order of concentration percentages from low to high of Mg<Ca<Na. The right triangle displays an order of anion concentration percentages from low to high

of $Cl < HCO_3 < SO_4$. The dominant cations are Ca and Na, and the dominant anions are HCO_3 and SO_4. The diamond-shaped trilinear plot where the percentage values of cations and anions intersect along lines from the respective ion triangles indicate several different water types. The predominant water type in the SMC SI samples is a Ca-Mg-Na/Cl-SO_4 water. Mixed ion water types of Ca-Mg-Na/HCO_3-Cl-SO_4 are also present.

Grouping of sample values are apparent in the trilinear diagram. Sample numbers SMC-08, -09, -10, -11, -12, 13, -14, -17, and -34 form a group of samples that represent a Ca-Mg-Na/SO_4 water type that is also elevated in TDS. With the exception of SMC-17, SMC-32, SMC-33, and SMC-34, this group of samples and their water type with elevated TDS suggest these samples (and associated well completions) likely represent the Qal aquifer hydrostratigraphic unit. Based on trilinear diagrams, and information presented earlier: sample locations that have CaMg-Na/SO_4 water type and a TDS of 1,000 to 3,000 or more mg/l are qualitatively assumed to yield water from the Quaternary alluvial aquifer. The remainder of the sample location water types is either a mixed-ion type water or a Na-Ca-Mg/SO_4-HCO_3 water type. The latter two water types suggest a bedrock hydrostratigraphic unit because of their difference in water type and overall lower TDS concentration. These latter water types could represent the Jurassic Morrison Formation, the Cretaceous Dakota Sandstone, and undifferentiated Jurassic-Triassic units like the Chinle Formation.

The report by Brod and Stone (1981) describes the interpretation of the ground water quality in the Ambrosia Lake-SMC area based on the sample results from 34 wells. The average overall TDS was 834 mg/l in that study. The domestic wells in the San Mateo community provided the best water quality; where as, those wells in the vicinity of the junction of highways 509 and 605 provided the poorest quality. San Mateo community wells produced water from the Menefee Formation, and had an average TDS of 400 mg/l. Wells in the vicinity of the highway 509-605 junction produced water mainly from the Westwater Canyon Member of the Morrison formation, and had an average TDS concentration of approximately 2,000 mg/l. The alluvium, Dakota Sandstone, and Westwater Canyon Member yield a Na-HCO_3-SO_4 water. The Menefee and Point Lookout Sandstone yield a Na-HCO_3 water. The minor aquifers units like the Dalton Sandstone Member of the Crevasse Canyon, Mancos Shale, and Bluff Sandstone yield a Na-SO_4 water type. The proportions of the ionic constituents in the water bear no consistent relationship to supposed depositional environments of the aquifer materials. The water chemistry depends more on the diagenetic history of the deposits, such as the influx of carbonate material, and on local conditions such as ground water recharge and movement.

In the investigation by Brod (1979), the results of ground water chemistry interpretation using trilinear diagrams indicated that the average major ion composition of the alluvium, Dakota Formation, and the Westwater Canyon were nearly the same, a mixed-ion water type (see Figure 31). Water samples from the Menefee Formation were observed to have a greater concentration of HCO_3 compared to the other formations, and the difference in chemical composition for this aquifer unit was visible in the trilinear diagram. The Hydrologic Sheet 2 in the report by Brod and Stone (1981) contains a significant amount of geologic information and more ground water sample results for the Ambrosia Lake-SMC area than this investigation. The Brod and Stone report data should be closely reviewed and extracted into a master database for the GMD area to provide: more confidence in the interpretation of hydrostratigraphy; more ground water sample locations; a basis for comparison of historical and current water quality parameters; more detailed geology; and more insight in the formulation and implementation of future ground water investigations.

Kelly et al., 1980 also described water quality results in Ambrosia Lake area using trilinear diagrams. One of the important observations in this paper concerned changes in ground water quality and type over time as a formation was dewatered and leakage across hydrostratigraphic units occurred. Alteration of water quality in the Westwater Canyon Formation from mine dewatering appeared to be characterized by increasing TDS concentrations, particularly an increase in the SO_4 ion from downward recharge by the more Na+SO_4 enriched, higher TDS water in the Dakota Sandstone. Comparison of trilinear diagrams for SMC SI sample results to historical trilinear diagram results is challenging because the water chemistries

at some well locations are likely to have changed over time due to legacy dewatering, recharge across hydraulically connected aquifer units of different quality, and possibly more recent recharge as ground water conditions slowly return to pre-mining, pre-dewatering conditions.

Samples SMC-07, -16, -20, and -22 are not depicted in Figures 29 and 30 because the assignment of the wells to the Qal or Jmw hydrostratigraphic units could not be determined. These samples appear to represent bedrock aquifer units by their geographic location and major ion water type. Based on a quick review of the data and interpretation reported by Brod, 1979 and Brod and Stone, 1981, SMC-07 appears to be from a well completed in the Jmw unit. SMC-16 and -20 appear to be from wells completed in the Cretaceous Dakota Sandstone (Kd). SMC-22 appears to be from a well completed in undifferentiated Triassic Formation (Tr). Since the position of these samples overlap more than one general area for distinguishing water type groups when plotted in a trilinear diagram, more geochemical or hydrogeologic interpretation work is required to confidently assignment these sample locations to a hydrostratigraphic unit.

8.4   SMC SI Select Trace Metal Results

Sources that could potentially contribute to current ground water quality for trace metals are worth mentioning here. The 1975 EPA report on the sample results from locations in the Ambrosia Lake area noted that discharge from numerous mines and ion exchange then operating caused perennial flow in Arroyo del Puerto. Seepage from the tailings ponds at these facilities was evident from the vegetation present in the formerly dry washes. Seepage from settling ponds and open channels leading to the two principal drainages were poorly understood at the time EPA conducted sampling in the area. EPA conservatively concluded that wastewater from U mining and milling facilities infiltrated the shallow ground water system in its study area. In particular, the Marquez windmill sampling results indicated the shallow aquifer was contaminated with elevated concentrations of TDS, Cl, NH_4, NO_3, and Se.

Historical trace metal analytical data from the Ambrosia Lake Mining sub-district are found in the 1980 and 1986 NMEID reports. Ion exchange facilities at: 1) the United Nuclear–Homestake Partners Mill; 2) the Kerr McGee Western and Central Ambrosia Lake Mines; 3) United Nuclear Corporation Mines; and 4) the Kerr McGee Section 35 and 36 Mines discharged treated water directly to alluvial systems draining to the Arroyo del Puerto. The Ranchers Exploration and Development Company Johnny M Mine discharged treated mine water from settling ponds to a ditch that drained to the Rio San Mateo. NMEID sampled water in the arroyo and at the outfall in the late 1970s for total metals and radionuclides. Though the analytical results described in the NMEID 1980 report are for total metals, they indicate the drainages received mostly elevated metal concentrations attached to suspended sediments and some unknown fraction of dissolved metals. Over time and due to periods of high volume water discharge, the fraction of metals in the dissolved state may have been significant. Moreover, since investigations in the area of the SMC SI have not focused on the sediment mineralogy and geochemistry with respect to natural attenuation processes, such as adsorption-desorption, oxidation-reduction potential, metal oxide speciation, and mineral saturation-equilibrium, the character of dissolved trace element chemistry and mobility is largely unknown. Results from the 1980 NMEID report indicate that total trace element concentrations for As, Ba, Se, Mo, U, V, and Zn were often elevated in water discharged to the Arroyo del Puerto and SMC.

The 1986 NMEID report provided total metal contractions for six samples of natural runoff. Even though the 1986 data is from surface water samples in total concentrations, it suggests that surface water may be elevated in some metals such as Ba, Pb, Se, U, V, and Zn. It is possible that the samples of natural runoff may be contaminated by airborne dust from uranium milling operations, overburden and low grade ore piles, and tailings evaporation ponds. It is also possible that the rock materials on the land surface subject to overland flow during precipitation events contains naturally elevated levels of certain trace metals.

In the current investigation, many of the chemical values for trace metals tested below the laboratory detection limit such that an actual measured value was not reported. When the majority of samples reported chemical values below the laboratory detection, the detection limit was used in this analysis as

the average value for the parameter. Twelve trace metals (Ag, Al, Be, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, and Tl) were reported at less than the laboratory detection limit for all 33 samples. The CLP laboratory data should be carefully reviewed for factors that could contribute to the reporting of so many analyte concentrations as non-detectable to ensure that the results are accurate. Figure 32 presents the concentrations of seven trace elements (As, Ba, Mn, Se, V, Zn, and U) in ug/l at sample locations in the San Mateo Creek area, New Mexico.

Concentrations of seven trace metals were reported to be less than the reporting limits for a significant number of samples: As = 5 samples; Fe = 19; Mn = 16; Se = 5; U = 4; V = 24 and Zn = 16. Based on the analytical results from the SMC SI sampling event, it could be assumed that many trace metals are not present in ground water at levels that can be measured using standard laboratory methods either due to matrix interferences, or because these analytes truly have extremely low concentrations in the ground water. When sample analytical results were reported to be less than reporting limits NMED used values equal to 50% of the reporting limit for some specific calculations and graphical plots in this data analysis.

Dissolved As ranged from five samples reporting less than the detection limit of 2 ug/l to a high of 37.7 ug/l (SMC-13). The average dissolved As concentration was 8.5 ug/l. Seven samples exceeded the EPA standard of 10 ug/l.

Dissolved Ba ranged from eight samples reporting concentration minimums of 5 ug/l to a high of 288 ug/l (SMC-34). The average dissolved Ba concentration was 29 ug/l. None of the samples exceeded the EPA or the New Mexico Water Quality Control Commission (NMWQCC) ground water quality standards for Ba. The fairly common mineral, barium sulfate ($BaSO_4$) is likely to control the concentration of Ba in natural water Hem, 1985). Durfor and Becker (1964) reported the median concentration of Ba in public water supplies was 43 ug/l.

Most of the trace metal concentrations are unremarkable except for Mn, Se, U, and Zn. Dissolved Mn concentrations ranged from 16 samples reporting less than the detection of 5 ug/l to a high of 1,650 ug/l (SMC-32) which exceeds the NMWQCC ground water standard of 200 ug/l. The average dissolved Mn concentration was 66.4 ug/l. Measurable Mn concentrations were elevated in samples presumed to be from the alluvial aquifer at locations below the highway 605-509 junction and in the cluster of wells above HMC.

Dissolved Se ranged from less than the detection limit of 2 ug/l in five samples to a high of 618 ug/l (SMC-13). The average dissolved Se concentration was 95.1 ug/l. Eight samples exceeded the NMWQCC standard of 50 ug/l. Se values are observed to be highest in the sample locations from the alluvial aquifer hydrostratigraphic unit. Primarily one group of samples at the southern end of the SMC SI area have the highest Se values: SMC-11 (367 ug/l); SMC-12 (382 ug/l); and SMC-13 (618 ug/l). SMC-34 has a Se value of 434 ug/l and this sample is from an Alluvial aquifer monitoring well located between the mouth of Poison Canyon and the junction of highways 605 and 509.

Se is a relatively rare element and concentrations are generally very low (1 to 2 ug/l) in most natural waters (Hem, 1985). The low-temperature geochemistry of Se with particular references to Fe and U was studied by Howard (1977). Se occurs in oxidizing solutions as selenite (SeO_3) or selenate (SeO_4) ionic species, but it is easily reduced to elemental and nearly insoluble Se. Se may form the mineral ferroselite ($FeSe_2$) in the presence of Fe, and it may interact with or adsorb on ferric oxyhydroxides. Se minerals are associated with U sandstone ore deposits of the Western United States (Hem, 1985).

Dissolved Zn concentrations ranged from less than detection (<20 ug/l) in 16 samples to a high of 959 ug/l in sample SMC-17. The 17 samples with measurable concentrations of Zn averaged 247.7 ug/l, with the higher levels apparently associated with samples from bedrock wells. Alluvial wells SMC-10 and SMC-12 indicated elevated levels of Zn (81.9 and 481 ug/l, respectively) in the cluster of wells north of HMC; however, other samples from wells in the same area reported less than the detection limit. According to published literature, solubility data for Zn carbonate and hydroxide suggest that ground

water with 610 mg/l HCO$_3$ and a pH of 8.0 to 11.0 should contain less than 100 ug/l of Zn (Hem, 1972). Zn complexes of carbonate, SO$_4$, and Cl are probably controlling the occurrence of Zn in ground water.

8.5 SMC Dissolved Uranium Results

The 27 samples averaged 58.3 ug/l of U and ranged from less than the limit of detection (< 2 ug/l) to a high of 240 ug/l (SMC-13). Eleven samples exceeded the NMWQCC ground water U standard of 30 ug/l. The U values are observed to be highest in the sample locations from the Alluvial aquifer. Two areas in the SMC SI with the highest U values are the southern end of the SMC area (SMC-12, 163 ug/l– and SMC-13, 240 ug/l); the junction of highways 605 and 509 (SMC-20, 63.9 ug/l); and the area south of the highway junction (SMC-33, 166 ug/l and SMC-34, 117 ug/l). Figure 33 presents the dissolved U concentrations in ug/l for the SMC SI sample locations.

Comparison to the NURE ground water sample data for U in the Bluewater, Dos Lomas, and Milan 7.5 minute quadrangle indicate qualitatively that some water samples from the Alluvial aquifer had elevated U concentrations in the late 1970s, which still prevail to the current day. As noted in the Bluewater Mill SI, the natural concentration of U in most ground water was approximately 11 ug/l. No attempt is made in the SMC NURE sample data to qualitatively determine a natural concentration of U because most of the water samples were collected from wells assumed to be completed in the Alluvial aquifer. It is generally observed in the NURE water sample data and the data collected for the SMC SI that sample locations located away from the main drainages and farther up in the watershed contain the lowest levels of U, which is presumed to be representative of background to the basin.

8.6 SMC Correlation between U and Se

Analysis of the ground water data for the SMC SI indicates a positive correlation between U and Se concentrations. Figure 34 presents a plot of U vs. Se concentration for the SMC SI sample set and displays a trend line with an R^2 value of 0.7196. A positive correlation between U and Se concentrations is interesting because it suggests these two trace elements may become mobilized under similar geochemical conditions.

8.7 SMC Radiochemical Results

Gross alpha and gross beta results are not used in this investigation to evaluate and interpret ground water geochemistry in the SMC SI area. Fifteen samples exceeded the MCL for gross alpha of 15 pCi/l, and three samples exceeded the 50 pCi/l gross beta MCL. Elevated concentrations of gross alpha are assumed to come from dissolved U and ^{226}Ra, whereas, elevated concentrations of gross beta are assumed to come from ^{228}Ra or other beta emitting radionuclides not measured in the sample.

Ra and U are the primary radionuclides measured in both historical and the current investigations of the SMC area. The 1975 EPA reports and the 1980 and 1986 NMEID reports observed elevated concentrations of Ra and U in tailings water, tailings seepage, raw mine water, treated mine water, and discharge water. It is important to note that the EPA samples were filtered, whereas the NMEID samples were not. In this investigation SLD provided the laboratory results for Ra, and for some U, ^{234}U and ^{238}U isotope results. SLD radiochemical results are for total concentrations. Results from CLP and UNM were filtered at the time of collection and those results are reported as dissolved concentrations. Regardless, the ground water samples submitted to SLD contained very low levels of suspended sediment and the concentrations of Ra and U are assumed to be representative of dissolved levels. Some U concentration values reported by UNM and SLD for the same water sample show differences between the two laboratory results by several to a few tens of ug/l (e.g. SMC-09, -11, -12, -17, -24, -26, -32, -33, and -34).

^{226}Ra concentrations ranged from less than a detection limit of 0.01 pCi/l to a high of 2.9 pCi/l (SMC-32). ^{226}Ra concentrations averaged 0.37 pCi/l. ^{228}Ra concentrations ranged from a low of less than a detection limit of 0.08 pCi/l to a high of 3.91 pCi/l (SMC-32). ^{228}Ra concentrations averaged 0.75 pCi/l. Detection limits for Ra vary from sample to sample because of the influence of the amount of TDS in the sample.

Interestingly, it appears that the samples with the more elevated Ra concentrations occur in samples that are assumed to produce water from bedrock hydrostratigraphic units (SMC-07, -18, -20, and -32). This observation and assumption supports the geochemical behavior of Ra in that this radionuclide is seldom found far from the source because extreme low pH is necessary to mobilize Ra in the dissolved state. If Ra is present at elevated total concentrations it is because it has likely adsorbed to suspended particulate matter in the water.

8.8   SMC Uranium Isotope Results

Background information on the isotope geochemistry of U was described earlier in the Bluewater Mill SI uranium isotope section and is not repeated here. The approach described by Zielinski et al., 1997 is applied in the analysis of the SMC U isotope sample results.

Figure 35 is a plot of the U concentration in ug/l and AR for the 18 samples from the SMC area. Figure 36 is a plot of the reciprocal of the U concentration in ug/l and AR for the 18 samples from the SMC area. **Note that, unlike the study by Zielinski, there are no SMC SI samples of actual raffinate as in Figure 11 to provide one of the anchor points for a mixing line end member.** In Figures 35 and 36 the AR range from the samples of raffinate in the Zielinski paper are used to represent the possible AR range for the SMC raffinate sources since it is assumed to have a ratio close to 1.0. From here forward, the paper by Zielinski and the results presented in Figures 19, 35, and 36 are used to provide an interpretation of and suggestion for the source of U in some of the samples from the SMC investigation.

In Figures 35 and 36 three groups of samples are apparent. The first group, samples SMC-07, -08, -18, -31, and -32 are unique because the levels of dissolved U are low or less than the laboratory limit of detection. These five samples display a large range of AR values that range from 0.98 to 7.67. The low U concentration and large range of AR values for this first group of samples are interpreted to be representative of local background ground water U geochemistry. Based on the assumed and unknown hydrostratigraphic units, the first group of samples appears to produce water from bedrock aquifers (Jmw and Cretaceous sandstones).

The second group, samples SMC-04, -10, -20, -21, -22, -23, -24, and -28, are unique because their U concentrations range from 5.8 to 73.6 ug/l and average 35.2 ug/l. These eight samples have AR values between 1.3 and 2.5. These samples appear to indicate possible background U conditions, mixtures of more than one source of U not necessarily anthropogenic, or samples that reflect geochemical processes that shifted the original U isotopic ratios away from the value of 1.0. Based on the assumed and unknown hydrostratigraphic units, the second group of samples may produce water from bedrock aquifers, primarily the Jmw unit.

The third group, samples SMC-11, -12, -13, -26, and -33, are unique because their U concentrations are elevated, and their AR values are very low and close to the upper range of the raffinate AR defined by Zielinski et al., 1997. The U concentration in these five samples range from 188 to 613 ug/l and average 363.4 ug/l. These five samples have U concentrations one order of magnitude greater than the other two sample groups. The AR values for this third group of samples range from approximately 1.19 to 1.51. Based on the elevated U concentrations and low AR values, the third group of samples is interpreted to represent ground water that is possibly contaminated by raffinate waste water from the U milling activities in the SMC area. It is also important to note that these five sample locations are assumed to produce water only from the alluvial aquifer (Qal). Historically, the alluvial aquifer was recharged by discharges from the U mines and mills that released water into surface drainages such as the Arroyo del Puerto and SMC. Evaluation of recharge of the bedrock aquifers has occurred from legacy discharges in the surface drainages was not possible by this method and so few samples to evaluate.

An attempt was made to identify mixing lines and AR values to define background water sample groups following the technique employed by Zielinski, but using a correlation between U and Se concentrations instead of U and Mo. Unfortunately, the attempt to use the correlation between U and Se in the manner that Zielinski used U and Mo appears to be unsuccessful.

8.9   SMC Stable Isotope Results

Background information on the stable isotope geochemistry of water was described earlier in the Bluewater Mill SI stable isotope section and is not repeated here. Seventeen unique sample locations across the SMC study area were selected for stable isotope sampling and analysis of O, H, C, and S. Table 10 contains the results of isotopic measurements for ^{2}H, ^{18}O, ^{13}C, and ^{34}S.

8.9.1   *Oxygen and Hydrogen Isotopes*

Figure 37 is a stable isotope plot of δ^{18}O vs. δD (o/oo) of 17 ground water samples from the SMC SI, plotted with the Craig meteoric water line, New Mexico. Two of the samples displayed are duplicates of other samples.   The differences in isotopic concentrations for samples SMC-11/SMC-35 and SMC-26/SMC-36 indicate the laboratory analysis was slightly erroneous for reasons unknown at this time. Otherwise, Figure 37 shows that the samples display a spatial variation in isotopic composition, which suggests the ground water system is complex and not easily explained with the small number of samples that were collected in this SI. Delta ^{18}O values range from -13.12 o/oo to − 8.17 o/oo. Delta D values range from -98.3 o/oo to -57.8 o/oo. Average δ^{18}O and δD values are -73.55 o/oo and -9,92 o/oo, respectively.   The position of the isotope values beneath the ends of the Global Meteoric Water Line suggests that there may be an evaporation component in the sample isotopic composition. Sample SMC-07 and SMC-31 have the most negative (depleted) isotopic values suggesting sources of ground water for these wells may include isotopically-light precipitation recharge, possibly winter precipitation or snow. Samples SMC-08 and SMC-10 have the most positive (enriched) isotopic values, suggesting these sources of ground water may have received isotopically heavier recharge, possibly summer precipitation or surface water that was evaporated prior to infiltration to the water table. Since SMC-08 and -10 are sample locations assumed to produce water from the Qal unit, these result may reflect that Alluvial ground water is subject to seasonal evaporation since the water is in an unconfined state and open to the atmosphere.

Samples that are more positive in value for δD and δ^{18}O are considered to be more enriched due to evaporation-fraction of lighter isotopes and possibly a water source that has a longer flow path history than more depleted-lighter (more negative) sample values. SMC-07 and SMC-31 have the most negative values of δD and δ^{18}O, and these sample values plot at the left side of the chart. These sample locations are the highest in elevation, suggesting that their water history is short (young) and their source of recharge is probably snow melt water or cold weather storm precipitation (i.e., depleted in the heavier isotopes). The rest of the sample values in Figure 37 are assumed to be predominantly alluvial aquifer and/or bedrock water samples that plot along a local, unknown meteoric water line.

8.9.2   *SMC Carbon Isotopes*

Background information on the stable isotope geochemistry of C was described earlier in the Bluewater Mill SI carbon isotope section and is not repeated here.   For the purpose of this investigation, 16 samples were collected and analyzed for δ^{13}C. The δ^{13}C values range from -14.38 to -5.57 o/oo, and the average δ^{13}C value is -8.51 o/oo. The range of δ^{13}C values for the SMC SI set of ground water samples is depicted in the area of the red rectangle.   The δ^{13}C content in the samples appears to be in the range expected for marine and freshwater carbonates and suggests that soil zone CO_2 contributes a significant amount of the aqueous carbon in some of the samples. Figure 38 presents the range of δ^{13}C values in different types of carbonate reservoirs and the range of δ^{13}C values for ground water samples from the SMC SI (after Eby, 2004).

8.9.3   *SMC Sulfur Isotopes*

Background information on the stable isotope geochemistry of sulfur was described earlier in the Bluewater Mill S isotope section and is not repeated here.   Fifteen samples of ground water were collected and analyzed for the δ^{34}S concentration in the SMC area.   The 15 samples had δ^{34}S concentrations that range from -24.97 o/oo to +9.09 o/oo. The average δ^{34}S concentration in the 15

samples was -8.45 o/oo. Samples SMC-18 and SMC-28 have positive $\delta^{34}S$ values, whereas the remaining samples have negative $\delta^{34}S$ values. The two samples with positive $\delta^{34}S$ values are interpreted to have marine carbonate rock as the source of sulfur. The samples with negative $\delta^{34}S$ values are suggested to have a biogenic origin source rock that contained sulfur enriched in ^{32}S and depleted in ^{34}S. Figure 39 presents a comparison of biogenic and hydrothermal $\delta^{34}S$ sulfur isotope values from various uranium ore deposits in the western United States and Grants Mining District (after Jensen, 1963). For comparison, the range of $\delta^{34}S$ values for the SMC ground water samples are shown in the area defined by the red rectangle. Figure 40 presents SO_4 concentrations compared to $\delta^{34}S$ sulfur isotope values for the 15 ground water samples from the SMC area. Figure 40 indicates that two of the samples with highest SO_4 concentration (SMC-13 and SMC-11) also have the lowest $\delta^{34}S$ sulfur isotope values (depleted in the heavier S isotope). SMC-13 and SMC-11 are assumed to be well locations in the Qal unit. It is observed that the S isotopic composition in these two samples is similar to the range of $\delta^{34}S$ values from the study by Jensen, 1963, which was based on analysis of ore samples. The similarity between the $\delta^{34}S$ values in the SMC SI ground water samples and the Jensen, 1963 study is interesting, but inconclusive as to to the origin of S in the SO_4 in Qal ground water samples from the SMC area.

8.10   San Mateo Creek SI sample analysis Conclusions and Recommendations

Tables 4 and 5 present historical water sample data that suggest surface water drainages associated with Arroyo del Puerto and SMC received U mining and milling discharge waters that were elevated in radioactivity (Ra) and metals (Se, U, V). These discharges are assumed to have recharged the alluvial aquifer and possibly bedrock aquifer units in the SMC study area.

Water levels in alluvial aquifer wells rose as much as 50 feet during the peak periods of mine dewatering in the 1950s and late 1970s. Since mine dewatering ended, recharge of the alluvial aquifer has decreased and water levels have declined. Water levels in well OTE-1, below the confluence of Arroyo del Puerto and SMC declined at an average rate of 2 feet per year from 1978 to 1982 (Gallaher and Cary, 1986). With the exception of the Morrison Formation and Dakota Sandstone in the Ambrosia Lake area, bedrock aquifers such as the Morrison Formation Westwater Canyon Member, the Dakota Sandstone, Mancos Shale, and Menefee Formation may have received very little recharge from mine dewatering compared to the volume of water recharging the alluvial aquifer.   Since mine dewatering and discharge operations stopped in the 1980s, it is possible that these deep bedrock unit aquifers presently have static water levels approximating those of pre-mining discharge conditions. It is unknown if water levels in the Qal have declined to levels representative of pre-mining conditions.

As shown in Table 3 the NURE data from the Grants Special Study suggests that some wells below the junction of state highways 605-509 and above HMC contained elevated U concentrations. The NURE data at sample locations presented in Figure 2 indicate that U levels are very low at sample locations (background) above U mining-milling facilities in the SMC study area. The estimated average U concentration in ground water samples that are assumed not to be contaminated by mining-milling discharges is less than 5 ug/l.

Well construction information contained in Table 7 presents the limited amount of data available for wells that were sampled in the SMC SI area. A group of five wells in the alluvial aquifer north of HMC was used to calculate an average well depth (90 ft) and average SWL (38 ft). Qualitatively, Qal wells are no more than 130 ft deep, and bedrock wells are at least 130-150 ft deep to several hundred feet at some locations. Qualitatively, the farther the well is located away from the alluvial drainage channel, the more likely the well was completed in a bedrock hydrostratigraphic unit(s). Alluvial wells may draw water from than one hydrostratigraphic unit. The absence of SWL measurements over time in any of the Qal wells creates a huge data gap in the understanding of the ground water flow system. The question about whether SWLs in the Qal wells have returned to pre-mining discharge levels remains unanswered because there has been no consistent basin wide monitoring program during and after the period of legacy uranium site operations. Such data would directly pertain to the potentials for episodic migration of contaminants along the Qal ground water flow path, as well as for adsorption-desorption of metals and radionuclides to Qal sediments.

In early 2009 NMED collected ground water samples for analyses of metals, general chemistry, and radioactivity from 27 unique locations, and 17 samples among these 27 for specific isotopic analyses in an effort to characterize the ground water quality and flow system in the SMC area. As presented in Table 10, the average TDS concentration for the set of samples was approximately 1,370 mg/l, and appears to be highest in Qal wells. The average pH of the water was slightly alkaline at approximately 7.6. Na and SO_4 were highest among major ion concentrations. Six samples had a cation-anion balance error of greater than 10%. Minor ion concentrations were generally low for F and averaged less than 1.0 mg/l. Concentrations of NO_3+NO_2 averaged approximately 5.5 mg/l and are assumed to be higher in the Qal wells (9.5 mg/l average). Concentrations of NO_3+NO_2 in wells assumed to be completed in bedrock hydrostratigraphic units averaged less than 1.0 mg/l. Elevated concentrations of NO_3+NO_2 above background levels. in Qal wells suggest an anthropogenic component.

The majority of other minor constituents and trace elements for which the ground water samples were analyzed reported concentrations that were generally less than detection limits (Ag, Al, Be, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, and Tl). Since only one water sample (SMC-26) reported a concentration of 72.8 ug/l of Mo, an analysis similar to the one employed by Zielinski is not possible for the SMC SI. Laboratory results for dissolved Fe reported less than the reporting limit of 25 ug/l in 19 samples. Apparently, dissolved Fe does not occur in an oxidized form (FeO) that would complex with dissolved U in most of the ground water in the SMC area.

TDS concentrations generally increase in the direction of the alluvial ground water flow path from the upper to the lower SMC basin. TDS concentrations are observed to be markedly higher below the State Highway 605-509 junction primarily because: 1) the sampled wells are assumed to be completed in the Qal unit; 2) historical data suggest ground water here was impacted by legacy U mining-milling discharge waters; 3) Qal ground water is in an unconfined system open to evaporation; and 4) the assumed longer ground water residence time has provided more opportunity for geochemical processes like dissolution, ion exchange, and mineral precipitation, all of which can increase TDS concentrations. The pH of ground water samples below the State Highway 605-509 junction is slightly more alkaline than above the junction. The concentration of NO_3+NO_2 in wells around the State Highway 605-509 junction, and in the cluster of Qal wells above HMC were higher than other samples in the study area. It is unclear if current NO_3+NO_2 levels are representative pre-U mining-milling levels. Use of nitrogen isotopes ($^{15}N/^{14}N$ or $\delta^{15}N$) could aid investigation of the origin of NO_3+NO_2 concentrations in these areas. Isotopic analysis of N in ground water may reveal a distinction among potential sources (U milling, agriculture, and domestic septic or leach field), and what concentrations are possibly representative of natural conditions.

Stiff diagrams of SMC samples are distinctly different for wells assumed or known to be completed in the Qal unit as compared to wells completed in bedrock aquifer units (e.g., Jmw). Stiff diagrams from Qal wells have a pendant flag shape with the nose on the left side and a flag tail on the right side. Stiff diagrams from bedrock aquifer wells have shapes similar to a thin rectangle. Stiff diagrams with skewed hour glass shapes are interpreted to be intermediate between these two shapes, suggesting that these wells may draw water from more than one hydrostratigraphic unit.

NMED initially thought that plotting ionic sample compositions in a trilinear diagram could help to discriminate hydrostratigraphic units for well completions. Unfortunately, since the major ion chemistry in many of the ground water samples is ionically similar, the resulting sample positions in the trilinear diagram show a wide, overlapping variation even though TDS concentrations are not similar. Many sample values plot in positions reflecting the dominant anions of HCO_3 and SO_4, and the dominant cations of Ca and Na. The dominant water type in the SMC SI samples is a Ca-Mg-Na/Cl-SO_4. Mixed ion water types of Ca-Mg-Na/HCO_3-Cl-SO_4 are also present. Samples that have a Ca-Mg-Na/SO_4 water-type and a TDS of 1,000-3,000 are assumed to be from wells that are completed in the Qal unit. The remainder of water samples is either a Na+K-Ca+Mg-SO_4-HCO_3 or mixed ion water type. These latter ground water types are suggestive of a bedrock hydrostratigraphic unit-- possibly the Jmw, Cretaceous Dakota Sandstone, and/or undifferentiated Jurassic and Triassic units. The earlier work by Brod (1979)

indicated the average major ion composition of water in the alluvium, Dakota sandstone, and Jurassic Morrison formation is a mixed ion water type that is chemically similar even through the units are different. More insight into the hydrogeology of the SMC area might be gained by careful review of the hydrogeologic information on Hydrologic Sheet 2 (Brod and Stone, 1981) to clarify and refine the interpretation of hydrostratigraphy in the study area.

Brief summaries of historical water sampling data from the Ambrosia Lake Mining sub-District were presented to demonstrate that the Arroyo del Puerto drainage had received discharges from legacy U mining and milling operations. Concentrations for 12 trace metals in the ground water samples collected for this investigation were not reported to exceed the respective analytical reporting limits. Only seven trace elements occurred in enough samples with concentrations above the respective analytical reporting limits to be useful in evaluating ground water geochemistry in the study area (As, Ba, Mn, Se, V, Zn, and U). The number of samples exceeding EPA drinking water standards or NMWQCC ground water standards in this group of trace elements were: As=5; Mn =1; Se = 8; and U = 11. Except for Se and U, the one time sample results for trace elements are mostly unremarkable

Se and U concentrations are observed or assumed to be highest in sample locations from the Qal unit. The average Se concentration in the sample set was approximately 95 ug/l. The average U concentration was approximately 58 ug/l. in the sample set. A positive correlation was observed between Se and U at a value of 0.7196, suggesting that these two trace elements are covariant and may mobilize in ground water under similar geochemical conditions. The area with the highest concentrations of Se and U is in the southern part of the study area in the group of assumed alluvial wells located north of HMC. Comparison of the NURE water sample results from well locations in the SMC alluvial channel to the U concentration results throughout this study area suggests that the Qal ground water quality was impacted in the late 1970s and remains impacted today. The average concentrations of Se and U determined by this investigation qualitatively suggest these metals are present above background levels.

Legacy radiochemical water sample results emphasized Ra and U as clear indicators of U mining-milling discharges; however, most Ra concentrations measured from ground water samples collected during this investigation were low. The average ^{226}Ra and ^{228}Ra concentrations were 0.37 pCi/l and 0.75 pCi/l, respectively. Interestingly, SMC-32, which is the closest sample in this investigation below the cumulative discharges of the 2 uranium mills and mines along the Arroyo del Puerto had the highest ^{226}Ra and ^{228}Ra concentrations at 2.9 pCi/l and 3.91 pCi/l, respectively. SMC-32 is reported to be completed in the Jmw unit (250 ft deep). Spatial evaluation of Ra data from this investigation suggests that bedrock hydrostratigraphic unit wells contain slightly higher concentrations of Ra than Qal unit wells.

Ra in solution exists only in the 2+ oxidation state, and its chemistry resembles that of Ba (Landa, 1980). The solubility product for $RaSO_4$, which is the presumed chemical form of Ra in sulfuric acid-leached tailings, is extremely low (K_{sp} = 4.25 X 10^{-11} at 20° C [Sedlet, 1966]). Ra does not appear to be a contaminant of concern in the ground water system of the SMC study area because it is relatively insoluble, does not tend to form soluble complexes with other ions, was easily precipitated out of acidic mill tailings by the addition of $BaSO_4$, and has a strong tendency to adsorb onto various mineral surfaces such as clays and other silicate minerals (Landa, 1980). Based on the water sample results from EPA, 1975, and the results from this investigation, Ra does not appear to be a radiochemical of concern or a reliable indicator of legacy U mining and milling impacts.

In contrast, U concentrations from this investigation indicate that this radionuclide is elevated in the ground water, and the geochemical conditions support transport of this metal in the aqueous environment. U transport generally occurs in oxidizing surface and ground waters as the uranyl ion, UO_2^{2+}, or as complexes of phosphate, carbonate, and sulfate (Landa, 1980 and Langmuir, 1978). U does sorb onto surfaces of silicate minerals (clays), organic matter, and oxides of Fe and Mn across a pH range of 5.0 to 8.5 (Langmuir, 1978). However, the sorption of uranyl ions may be reversible, and for U to be physically and chemically "fixed" requires reduction from U^{6+} to U^{4+} by the substrate material or by a mobile phase such as hydrogen sulfide, or H_2S (Kochenov et al., 1965; and Langmuir, 1978).

In a previous section of this paper, background information describing the theory behind using U isotopes to "fingerprint" sources of U in ground water samples was presented, and several examples were given, which included discussion of a site in southwest Colorado that was used for comparison and source data in NMED's investigation. Eighteen samples of ground water from various locations in the SMC study area were analyzed for concentrations of ^{238}U and ^{234}U. Sample AR values ($^{234}U:^{238}U$) were plotted against concentrations of dissolved U for each sample. The AR for U mill raffinate was used as a chemical end member to compare against the 18 samples in NMED's investigation (Zielinski, et al., 1997). Three distinct groups of water samples were identified: 1) background; 2) mixed sources of background and anthropogenic; and 3) anthropogenic. The third group of samples is interpreted to contain an anthropogenic component of raffinate waste water, possibly from legacy U milling discharges in the SMC area. The evidence for an anthropogenic component is the elevated dissolved U concentration and the low U AR values that are close to the upper range of the raffinate waste water from the study in southwest Colorado (Zielinski et al., 1997). This conclusion should be examined and reviewed by other geochemical experts, with the hypothesis subjected to a "proof-of-concept" investigation by repeat isotopic sampling and laboratory analysis at both the same and additional well locations in the study area. Laboratory resources at UNM, the EPA, and at Los Alamos National Laboratory (LANL) could provide the U isotopic analysis, as well as some additional professional geochemical expertise. Future investigations in the SMC SI area should continue to sample ground water locations for isotopic analysis of U to build a more in-depth geochemical data base, and to help fingerprint sources of ground water geochemistry.

The stable isotope results for concentrations of $\delta^{18}O$ and δD in 17 ground water samples from the SMC SI are interesting, but not very conclusive for identification of source waters or possible components of legacy U mining and milling discharge waters. This conclusion is partly due to the small number of samples that were collected in NMED's investigation, which likely represent too few parts of the hydrologic cycle to enable an explanation of a complex ground water system. The range of $\delta^{18}O$ and δD values in NMED's samples may represent both isotopically enriched water (possibly heavier isotopic fractionation caused by evaporation), and more isotopically depleted water (lighter isotopic fractionation caused by low temperature precipitation or snow at higher land elevations). Most of the ground water sample $\delta^{18}O$ and δD concentrations were similar and plotted close together in an x-y graph. Utilization of the $\delta^{18}O$ and δD isotopes in future investigations may be useful since samples are easy to collect, require no preservatives, and can be stored for more than a year if the sample containers are tightly sealed to prevent evaporation. Samples of $\delta^{18}O$ and δD from other parts of the hydrologic system (seasonal precipitation, surface water, infiltration, impacted ground water) would be helpful to better interpretation and quantification of the hydrologic balance in the study area.

Interpretation of the stable isotope $\delta^{13}C$ concentration values in the 16 samples collected and analyzed during this investigation is inconclusive and should be evaluated by an expert with a strong knowledge of carbonate geochemistry.

Utilization of stable isotope $\delta^{34}S$ concentrations was hypothesized to help identify the source of SO_4 in ground water in the SMC SI area. Interpretation of the stable isotope $\delta^{34}S$ concentration values in the 15 waters samples collected and analyzed during this investigation are suggested to have an isotopic composition similar to the S isotope results from a 1963 study of U ore rock samples from the Ambrosia Lake area (Jensen, 1963). The $\delta^{34}S$ concentrations in the ground water samples are predominantly negative (depleted in the heavier sulfur isotope), which suggests the S may have come from biogenic processes and geochemical conditions similar to the reducing environment that created the original U ore deposit. Since sulfuric acid leaching was performed to extract and concentrate U at mill sites in the Ambrosia Lake area, it was hypothesized that S isotopic analysis could help determine if the source of SO_4 in ground water in the study area may contain a sulfuric acid component. NMED's results are interesting but inconclusive, and the data should be reviewed and evaluated by a professional geochemical expert.

Table 11 describes the environmental issues, data gaps, and suggested solutions for characterizing, understanding, and better long-term monitoring of the SMC ground water system with a focus on the Qal aquifer.

9.0   Comparison of Bluewater and San Mateo Creek Data and Discussion of Results

In order to perform a general quantitative comparison of the two groups of ground water samples based on geographic location, some adjustment of the sample set contained within each group was necessary. The 2008 Bluewater Mill SI sample set consisted of 33 unique sample locations. Four sample locations were monitoring wells on the Bluewater uranium mill site (BW-25, -26, -27, and -28). Ground water from these four wells is assumed to be impacted by contamination from mill waste water, so they are excluded from group comparisons. Sample BW-35 is from a deep well located north of the HMC site and within the southern part of the SMC basin (see Figure 11). For this reason BW-35 is included in the group of SMC samples because its geographic location is more pertinent to the SMC SI area than the Bluewater Mill SI area. This adjustment leaves the Bluewater Mill SI sample set total number at 28 samples (33-5 = 28).

Of the 27 unique locations for the SMC area investigation, three water samples were from wells located in the southern part of the Bluewater Basin (SMC-03, -04, and -05), and not in the main part of the SMC area where the majority of sample locations exist (see Figure 25). Based on their geographic location, samples SMC-03, -04, and -05 are moved from the SMC SI sample set to the Bluewater Mill SI group of samples. The final tabulation of individual sample locations within each group of samples for comparison is: Bluewater SI area – 31 samples; and SMC SI area – 25 samples. Table 12 presents the average values of chemical parameters between the Bluewater and SMC SI sample groups. Figure 41 is a chart that compares the major ion average values between the two groups, and Figure 42 is a chart that compares the trace element average values between the two groups. A quantitative comparison of Ra, U, O, H, S, and C isotopic values between the two groups was not performed. For the Ra isotopic data, the values are low —close or equal to non-detect when the counting errors are considered. Or in the case of the U and other stable isotopes, the number of samples collected by NMED is a small subset of the total number of samples. The isotopic samples in each group are unequal in number and do not include enough samples for a representative, quantitative comparison. The isotopic results between the two sample groups will be compared and discussed qualitatively.

Table 12, Figure 41 and Figure 42 indicate the SMC SI sample group contains a higher average value compared to the Bluewater Mill SI sample group for the chemical parameters: pH, TDS, Ca, Na, SO_4, NO_3+NO_2, As, Ba, F, Fe, Se, Zn, and U. The Bluewater Mill SI sample group contains a higher average value than the SMC SI sample group for Cl and HCO_3. The Bluewater Mill SI sample group is more elevated in Cl and HCO_3 than the SMC SI sample group because the Bluewater Mill SI focused on wells that produce water from the SAG, which was formed in a marine seawater environment. The SMC SI sample group is more elevated in TDS and slightly more alkaline in pH than the Bluewater Mill SI group because of the greater number of shallow, unconfined alluvial wells among the SMC SI samples. Because alluvial wells included in the SMC SI are thought to have received recharge both from legacy uranium mining and milling discharges in the upper tributaries of the basin, and from a geologic terrain with commercial-grade uranium ore deposits, concentrations of Se and U are 11 and 5 times higher, respectively, than the Bluewater Mill SI sample concentrations for these trace elements. The radioactivity parameters of gross alpha, gross beta, [226]Ra, and [228]Ra are approximately 4 times higher in the SMC SI samples than in the Bluewater Mill SI samples.

In Figure 43 a comparison of the Bluewater Mill and SMC SI sample data is plotted in the trilinear diagram from the report by Brod, 1979. Figure 43 primarily indicates that ground water from the Bluewater Mill SI has a chemical composition that is distinctly different from ground water in the SMC SI area. Figure 43 shows that the majority of the Bluewater Mill SI samples plot in a tight group in the upper part of the diamond area, indicating a rather consistent ground water type enriched in SO_4+Cl.

Sample BW-32 plots in the area represented by SMC SI alluvial samples SMC-12 and -14; BW-32 appears to have a water composition more like the alluvial water as interpreted from the SMC SI sample set, rather than like the majority of samples from the Bluewater Mill SI, which focused on wells completed in the SAG. BW-25 is shown in this figure because it is chemically unique, and plots separately from the majority of samples in the SAG. BW-25 is described as the background well for the Bluewater Mill Site, but the chemical composition of water from this well is clearly unlike the 26 samples in the blue shaded area of Figure 43. Alluvial samples SMC-10, -11, and -13 plot in a small area of the upper right part of the diamond, indicating these are similar in chemical composition (Ca-Mg/SO_4-Cl). These three alluvial wells are located close together in the cluster of wells north of the HMC site. Alluvial samples SMC-12 and -14 plot in the middle, lower right side of the diamond, indicating that these samples have a chemical composition enriched in Na-K/SO_4-Cl. The three orange shaded areas for the Westwater Canyon unit samples indicate the chemical composition of water in this aquifer varies significantly depending on the locations and depths of the wells.

Comparison of the U isotopic data from the Bluewater Mill and SMC SI indicates 1) the range of ^{234}U:^{238}U AR values is generally lower in the Bluewater Mill SI samples than in the SMC SI samples; and 2) the SMC SI sample group includes several samples with low ^{234}U:^{238}U AR values and associated elevated U mass concentrations. Most of the Bluewater Mill SI samples are assumed to be representative of natural conditions and do not show the same geochemical composition as the SMC SI sample set. Careful inspection and comparison of the sample data points in Figures 20 and 35 suggest that most of the Bluewater Mill SI U isotope samples represent natural conditions with the exception of BW-34 and possibly BW-32. In the SMC SI data set, Figure 35 suggests that five samples (SMC-11, -12, -13, -26, and -33) may have impacts from U mill raffinate. Additional geochemical and isotopic work could implement a proof of concept for this hypothesis as to the source of U in samples with a low ^{234}U:^{238}U activity ratio and elevated U mass concentration.

Comparison of stable isotope data for $\delta^{18}O$ and δD between the two groups of samples indicates the SMC SI group displays a wider range of isotopic concentration-fractionation (slightly more enriched) than the Bluewater SI group because: 1) the SMC SI group contains a greater number of samples; 2) the majority of SMC SI samples are from the shallow, unconfined alluvial aquifer; and 3) several SMC SI samples are from locations that are higher in elevation than the Bluewater Mill SI samples. The limited $\delta^{18}O$ and δD sample data from the Bluewater Mill and SMC SI areas are a good start to further the geochemical interpretation of the hydrologic system within the SMC basin. To further the isotopic characterization of the hydrologic cycle and to understand the potential sources of recharge to the ground water system, samples of seasonal precipitation and surface flow in the study area would help to define end members and potential contributions to recharge.

The stable carbon isotope data indicate that the SMC SI sample group is slightly more depleted in $\delta^{13}C$ isotopes than the Bluewater SI samples. The stable S isotope data indicate the SMC SI samples are more depleted in the $\delta^{34}S$ isotope compared to the Bluewater SI samples because the source of S in SO_4 in the SMC SI samples is possibly from sulfide minerals of biogenic origin. This interpretation is hypothesized to relate to the biogenic reducing environment for the uranium ore deposition, which caused fractionation of sulfur isotopes. More geochemical evaluation is needed to interpret the $\delta^{34}S$ isotope data to determine if it can be used to distinguish sources of SO_4 in ground water.

10.0 Conclusions and Recommendations

The collection of ground water samples for the Bluewater Mill and SMC SI, and the preceding hydrogeochemical evaluation of laboratory results provide valuable insight into the ground water quality of the GMD. The data presented in this report create the foundation for future investigations, including future periodic sampling to monitor changes in ground water quality-chemistry over time. For example, samples BW-34 (August, 2008) and SMC-01 (March, 2009) were collected from the same well at different time periods, but have differing chemical compositions, notably the concentrations of dissolved

U. It appears that there may be a seasonal variation in the chemical composition of ground water at this location for reasons not understood at this time. The question arises as to whether these observed variations might be due to seasonal, agricultural pumping at wells in the down gradient vicinity of other areas of the basin.

Some of the weaknesses in the methodology used in these Site Investigations included the lack of properly sited and constructed monitoring wells. Subsequently, the data collected and analyzed in this report reflect the limitations of well construction, as well as the extant groupings of the well locations. More properly sited and constructed monitoring wells in key locations would help provide better representative samples in areas without wells, or in locations where the hydrogeology is complicated by structures and unknown geology. It appears the alluvial aquifer requires the highest level of future effort because it provided samples with the highest levels of TDS, metals, and elevated radioactivity, and is generally presumed to be directly impacted by wastes and discharges from legacy uranium extraction activities. The alluvium also is in hydraulic interconnection to bedrock aquifer units through geologic structure and stratigraphy, and so potentially presents an undesirable source of contaminated recharge.

Consideration of data from HMC is a major omission in this analysis of ground water sample results and geochemical interpretation for the SMC Basin. HMC is located on top of the San Mateo Fault Zone, and the potential migration of contaminants of concern in the shallow aquifers from this site down along fault structures to mix with deep ground water in the SAG may not be fully characterized. More detailed geochemical investigative work utilizing both an expanded list of analytes and various isotopes might be considered for HMC to confirm the current interpretation that site-derived impacts are not promulgated to the SAG .

As noted in the preceding conclusion and recommendation sections for the Bluewater Mill and SMC SI areas, more hydrogeologic data are required to understand the potential interaction between legacy contamination sources at U mine and mill sites, and the downgradient ground water systems. The characterization of possible legacy uranium site impacts to ground water in the Bluewater Mill and SMC SI areas would benefit greatly from updated potentiometric ground water elevation contour maps to help confirm and understand ground water flow directions and the potential for contaminant movement in the ground water system. Existing wells might be utilized to provide water level data, periodic geochemical sample analyses, and pump test data to help characterize the sources of ground water at particular wells, and the potential for hydraulic communication across hydrostratigraphic units and geologic structures. However, additional monitor wells will be needed throughout the SMC basin to adequately characterize possible impacts from legacy uranium sites in the area.

11.0   References

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Figure 1. Location map of the Bluewater and San Mateo Creek site investigation areas, Grants Mineral Belt, northwestern, New Mexico.
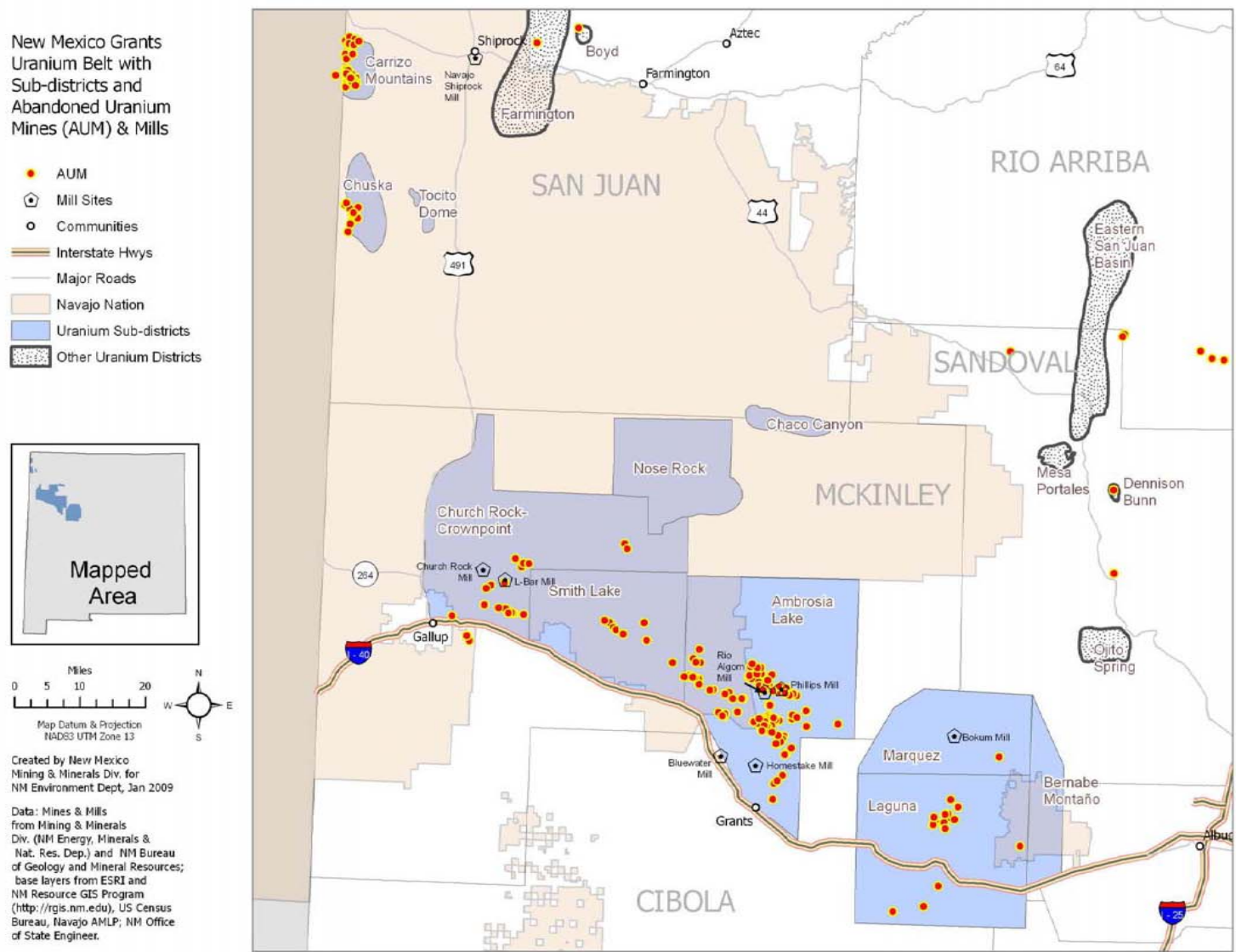
Figure 2. Location map and generalized ground water sampling transect of the Bluewater
site investigation area, New Mexico.
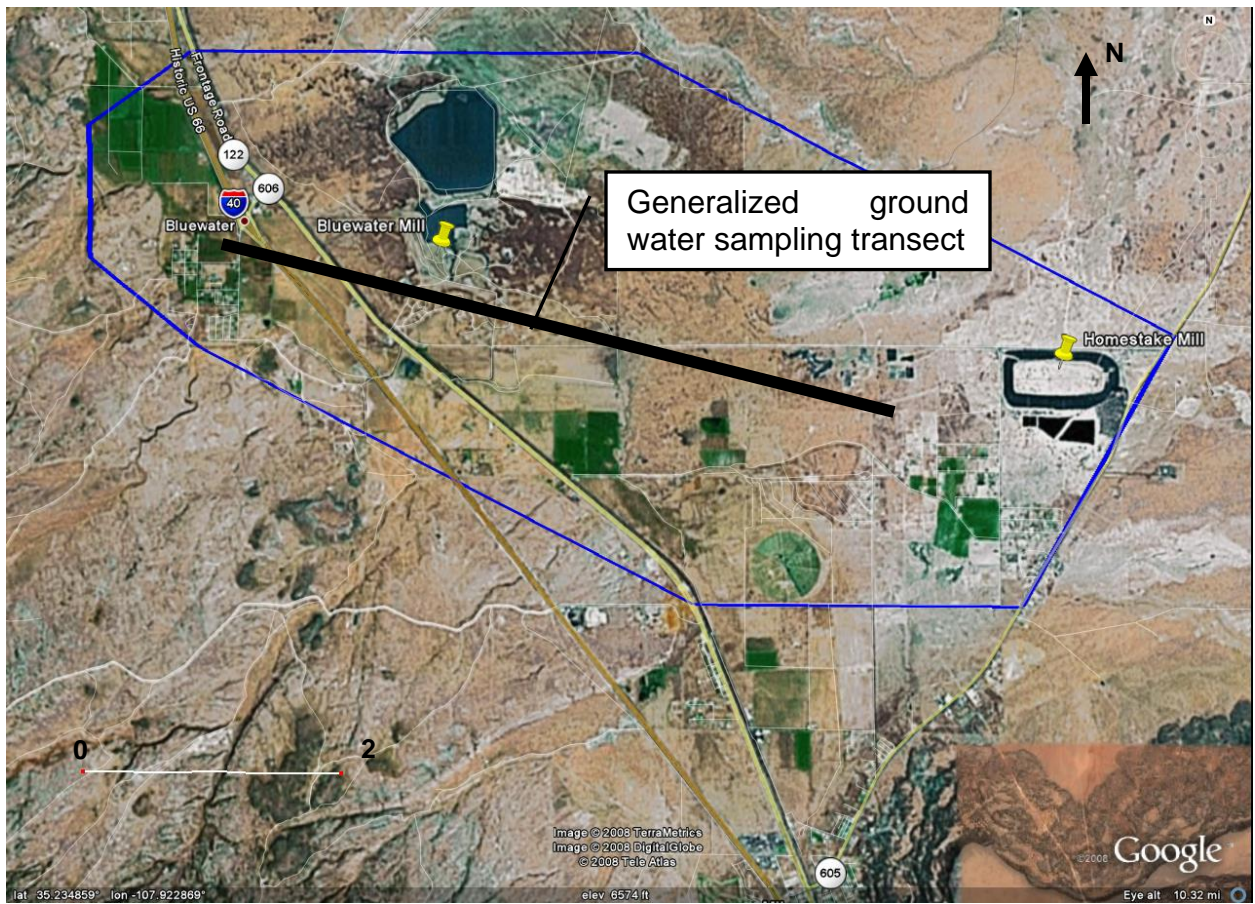
Figure 3. Map of all the ground water sample locations (2008-2009) in the San Mateo Creek Basin site investigation area, Grants Mineral Belt, New Mexico.
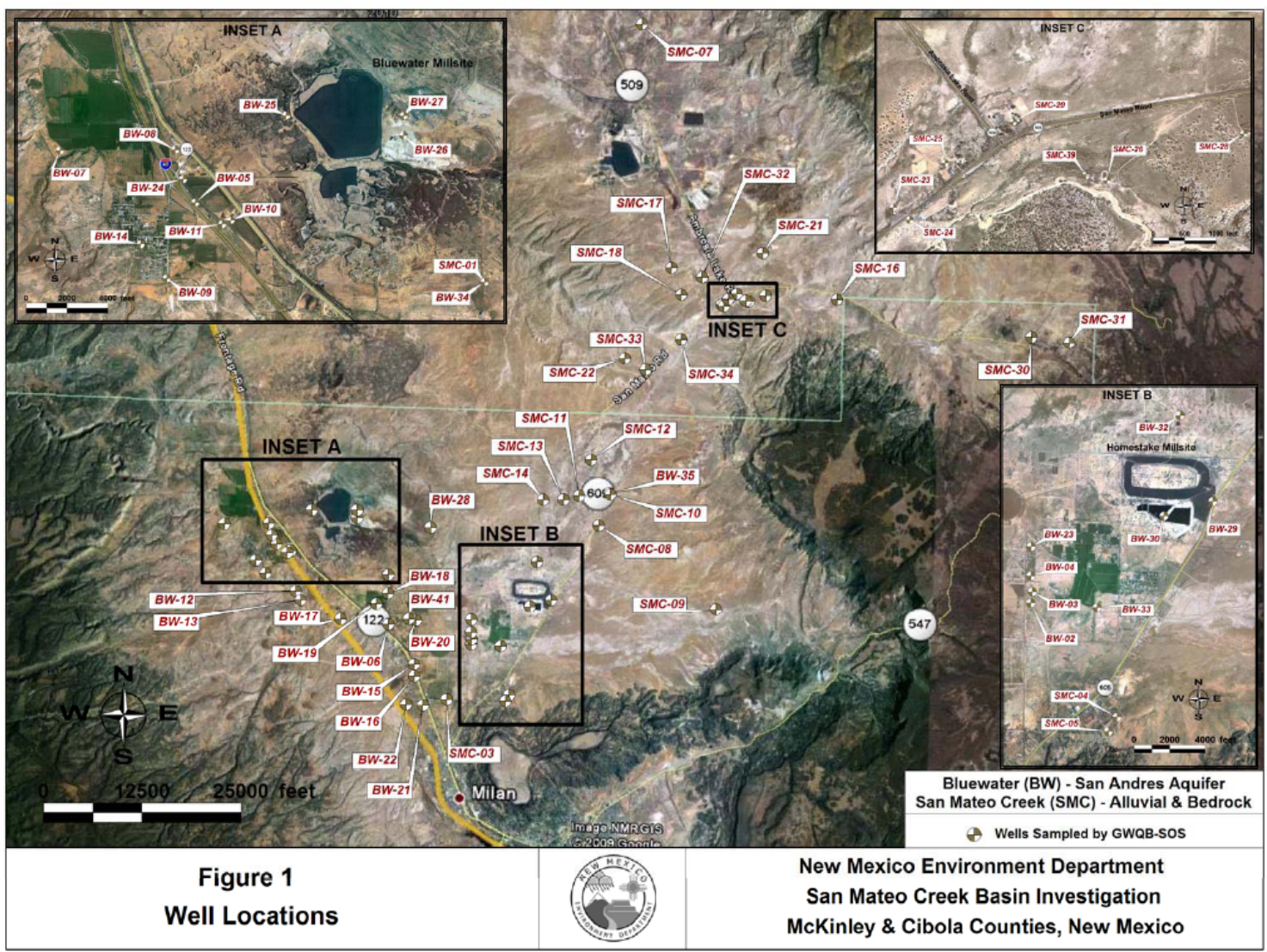
Figure 4. Well locations and water level contour map of the Grants-Bluewater area,
Cibola County, New Mexico (after Gordon, 1961).
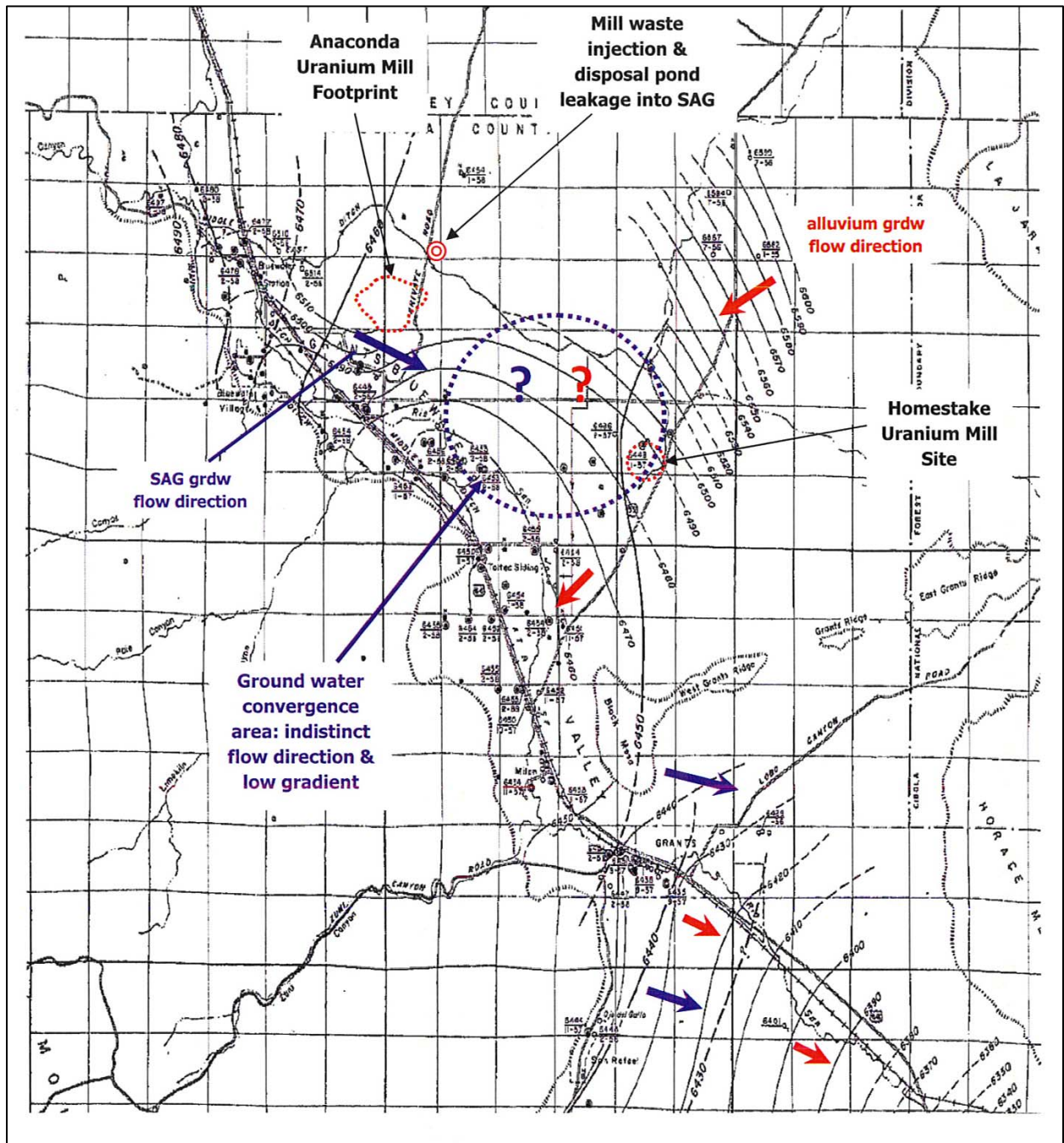
Figure 5. General geologic structure map of the Bluewater-San Mateo Creek area (after Kelly, 1963).

Figure 6. Geohydrologic map (1972) of the Grants area that illustrates the stratigraphic units; geologic structures; Anaconda disposal well location; local well locations; and ground water surface elevation contours in the alluvium-basalt and San Andres Aquifer, Bluewater area, New Mexico (after West, 1972).
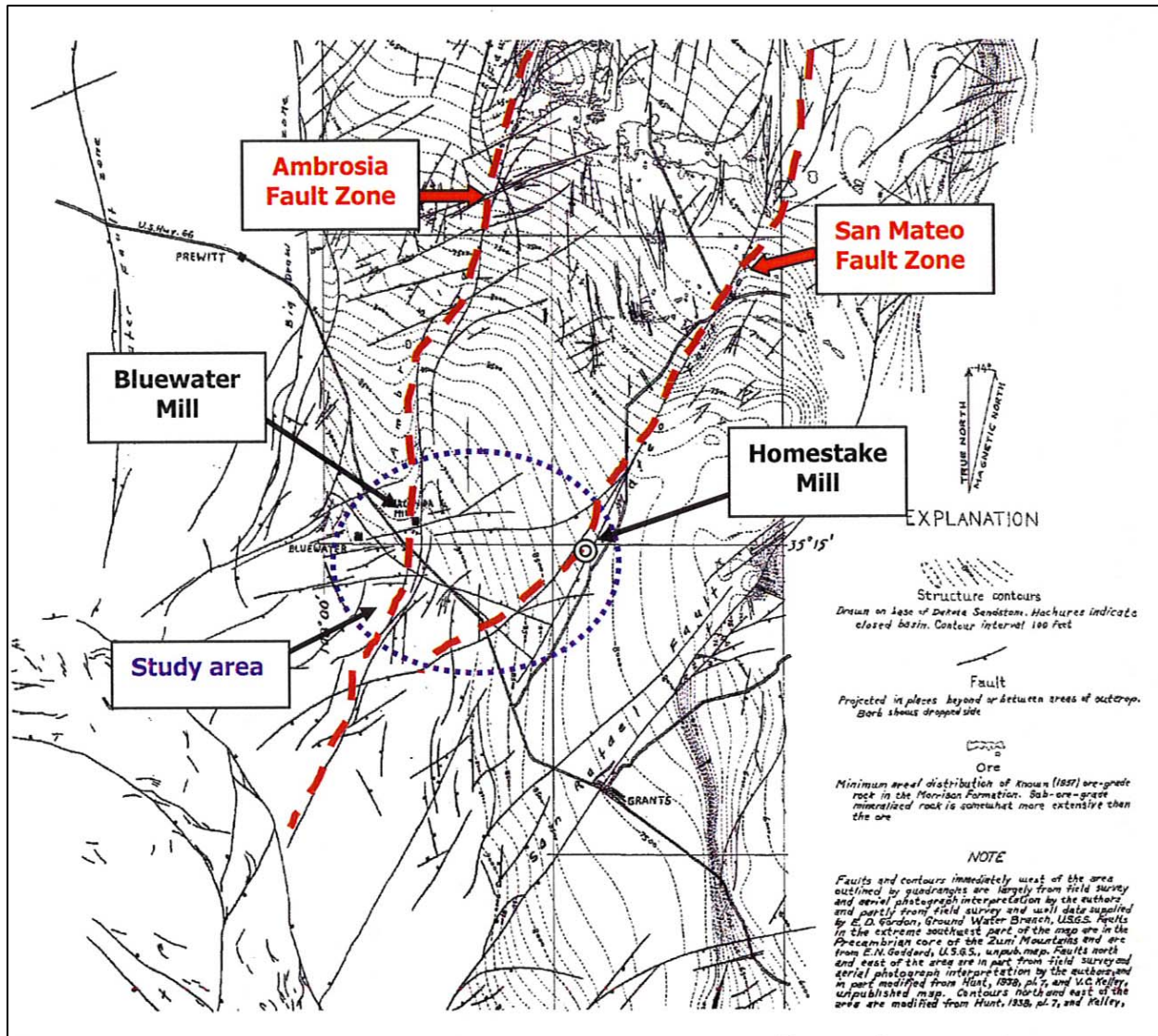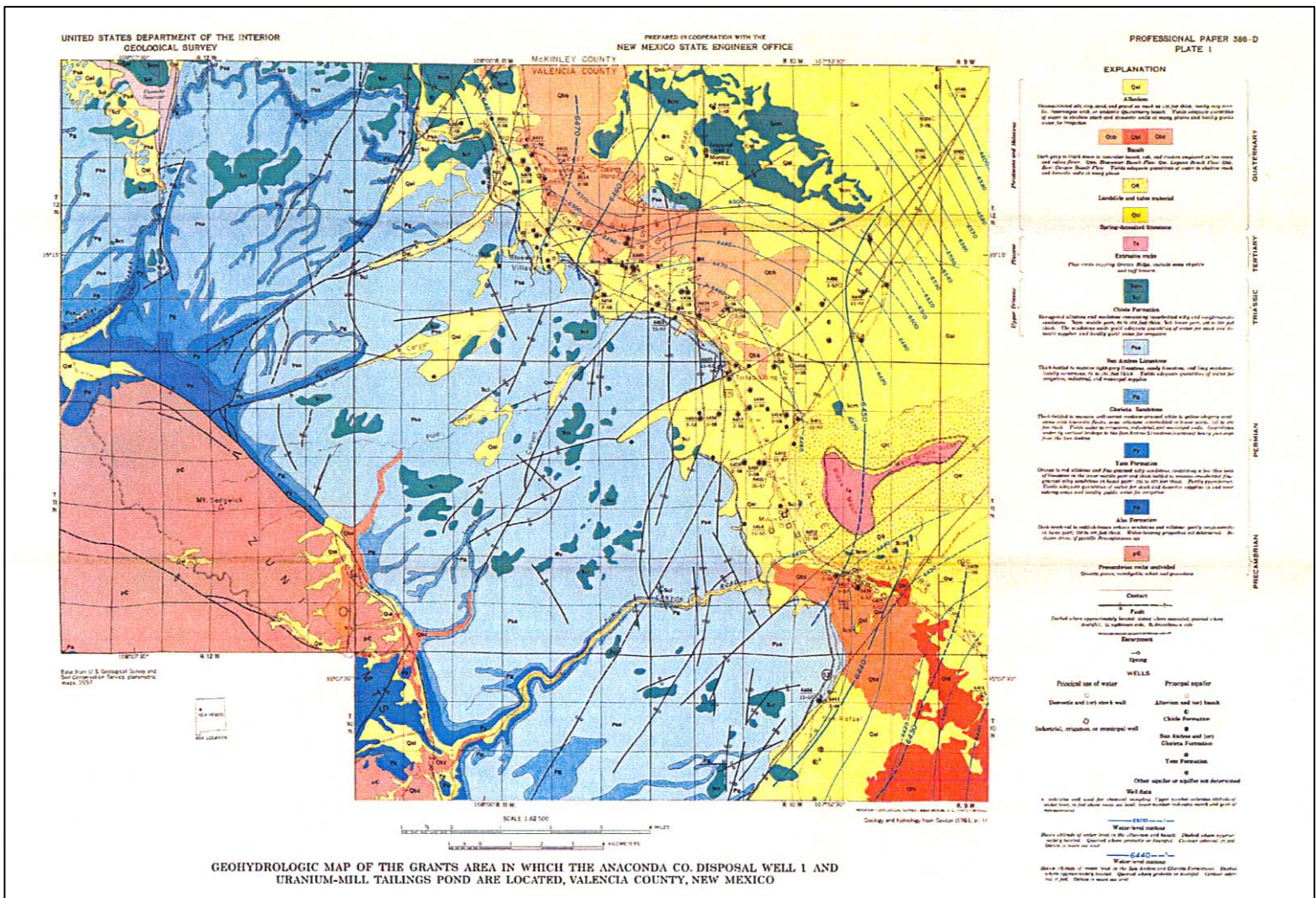
Figure 7. Radium (pCi/l), total dissolved solids (TDS), and chloride concentrations (1975) in mg/l in ground water near the United Nuclear-Homestake Partners Mill site, Bluewater area, New Mexico (after EPA,1975).
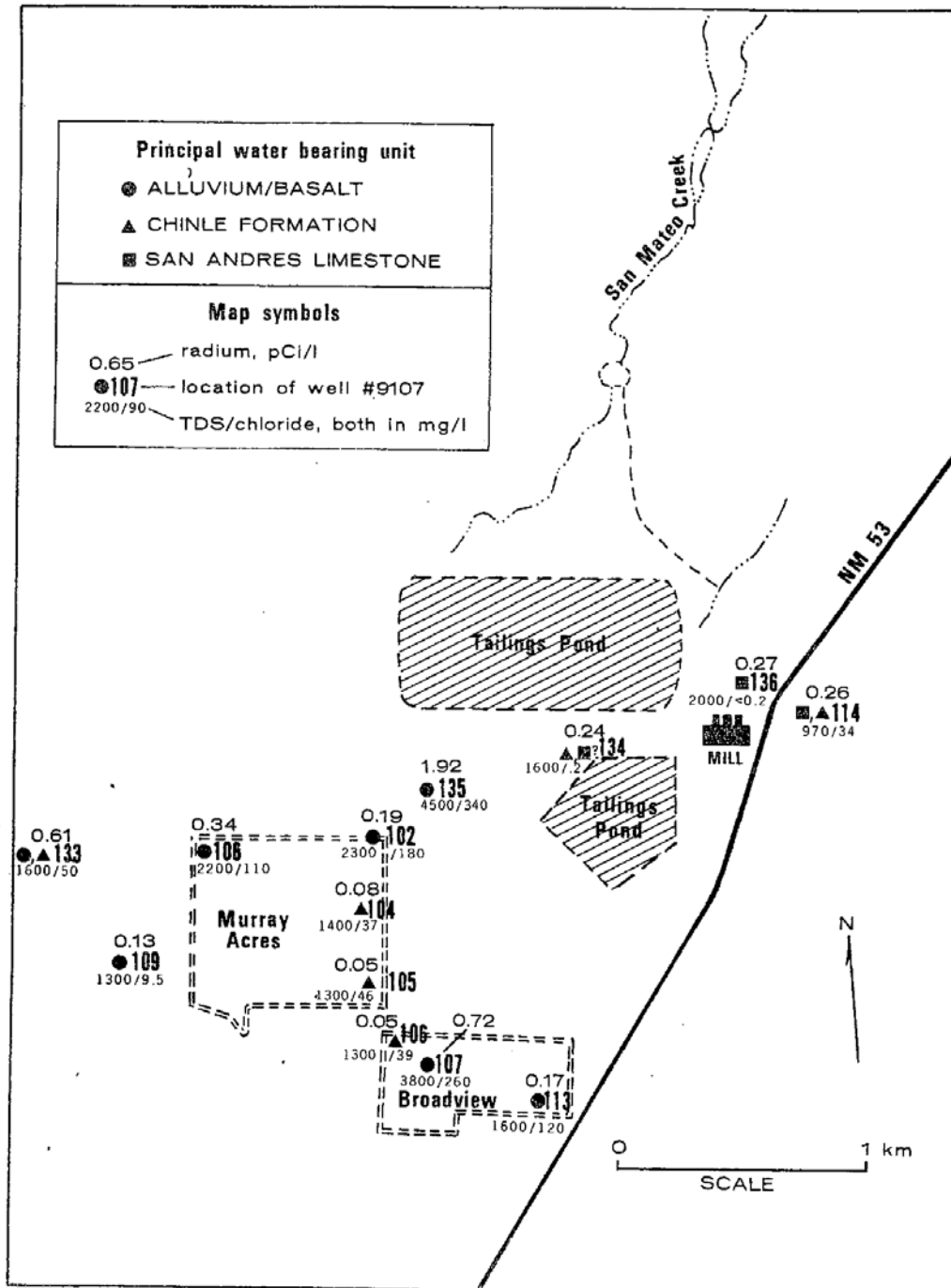
Figure 8. Radium (pCi/l) and nitrate (NO3) concentrations (1975) in mg/l in ground water in the Grants-Bluewater area, New Mexic (after EPA, 1975).

6.3
■121
0.05

0.17
■122
1.3

53
021
7.4

2.6
■,▲117
1.5

0.05
●124
0.8

0.26
●123
3.2

Tailings
Pond

Anaconda Mill

Bluewater

0.22
●125
0.95

0.11
■126
6.5

0.50
■118
9.0

0.18
●115
3.9

0.2
■119
5.4

0.27
■120
0.73

0.14
●129
2.5

0.21
■127
0.03

0.15
●128
1.4

I-40

N

0
1
2
3
4 km
SCALE

0.13
●101
4.2

0.09
●103
5.5

QUALITY OF WATER INJECTED			
Period	Radium	Nitrate	Source
1960 to 1965	292 pCi/l	23.7 mg/l as N	West; 1972
1966 to 1969	115 pCi/l		MRI; 1975

Milan

0.14
116
1.6

0.24
●111
3.4

0.42
●112
0.47

Grants

Principal water bearing unit
⊕ ALLUVIUM/BASALT
▣ SAN ANDRES LIMESTONE
▲ GLORIETA SANDSTONE
✗ YESO FORMATION (injection)

Map symbols

0.18 — radium, pCi/l
●127 — location of well #9127
3.8 — nitrate plus nitrite, mg/l as N

Figure 9. Google Earth map of the 1978-79 NURE ground water sample data locations and uranium values in ug/l, Bluewater, Milan, and Dos Lomas 7.5 minute topographic quadrangles, Bluewater area, Grants Mineral Belt, New Mexico.

Figure 10. Google Earth map of the 1978-79 NURE ground water sample data locations and uranium values in ug/l, Bluewater, Milan, and Dos Lomas 7.5 minute topographic quadrangles, San Mateo Creek area, Grants Mineral Belt, New Mexico.
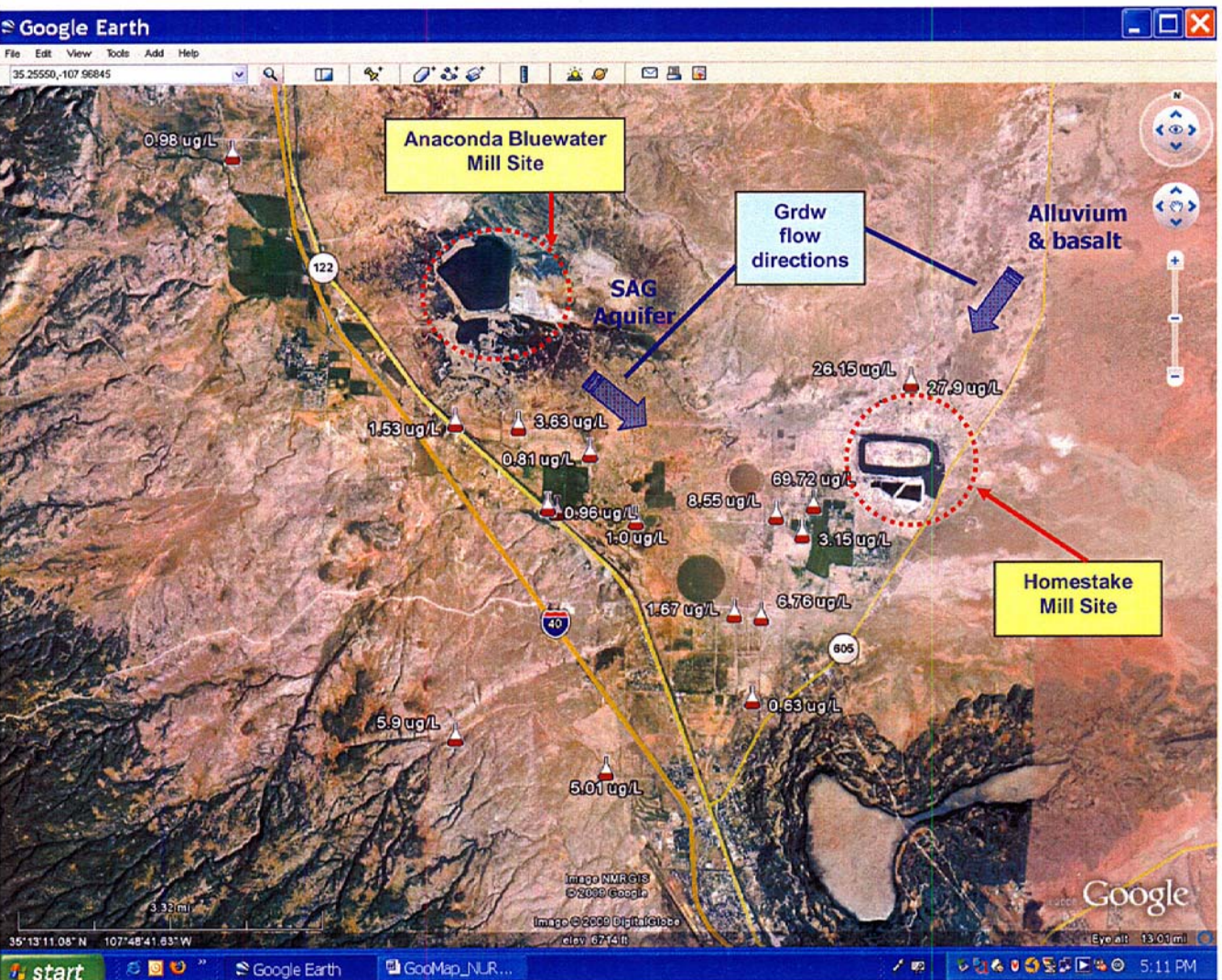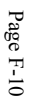
Figure 11. Ground water sample locations in 2008 for the San Andres Aquifer in the Bluewater area, Grants Mineral Belt, New Mexico.
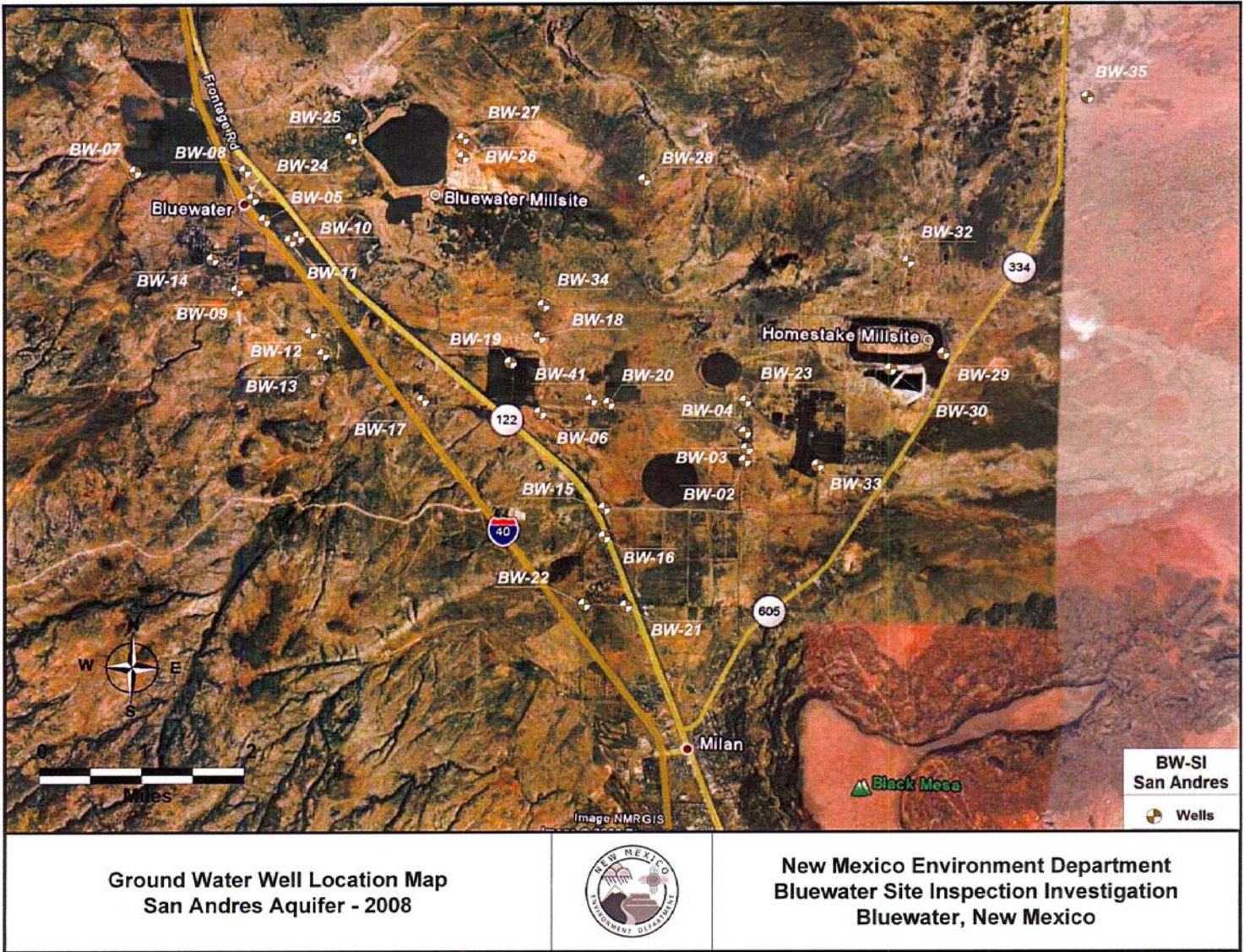
Figure 12. Chart of major ion and TDS concentrations (2008) in mg/l for sample locations along the assumed ground water flow path from west to east, Bluewater area, New Mexico.
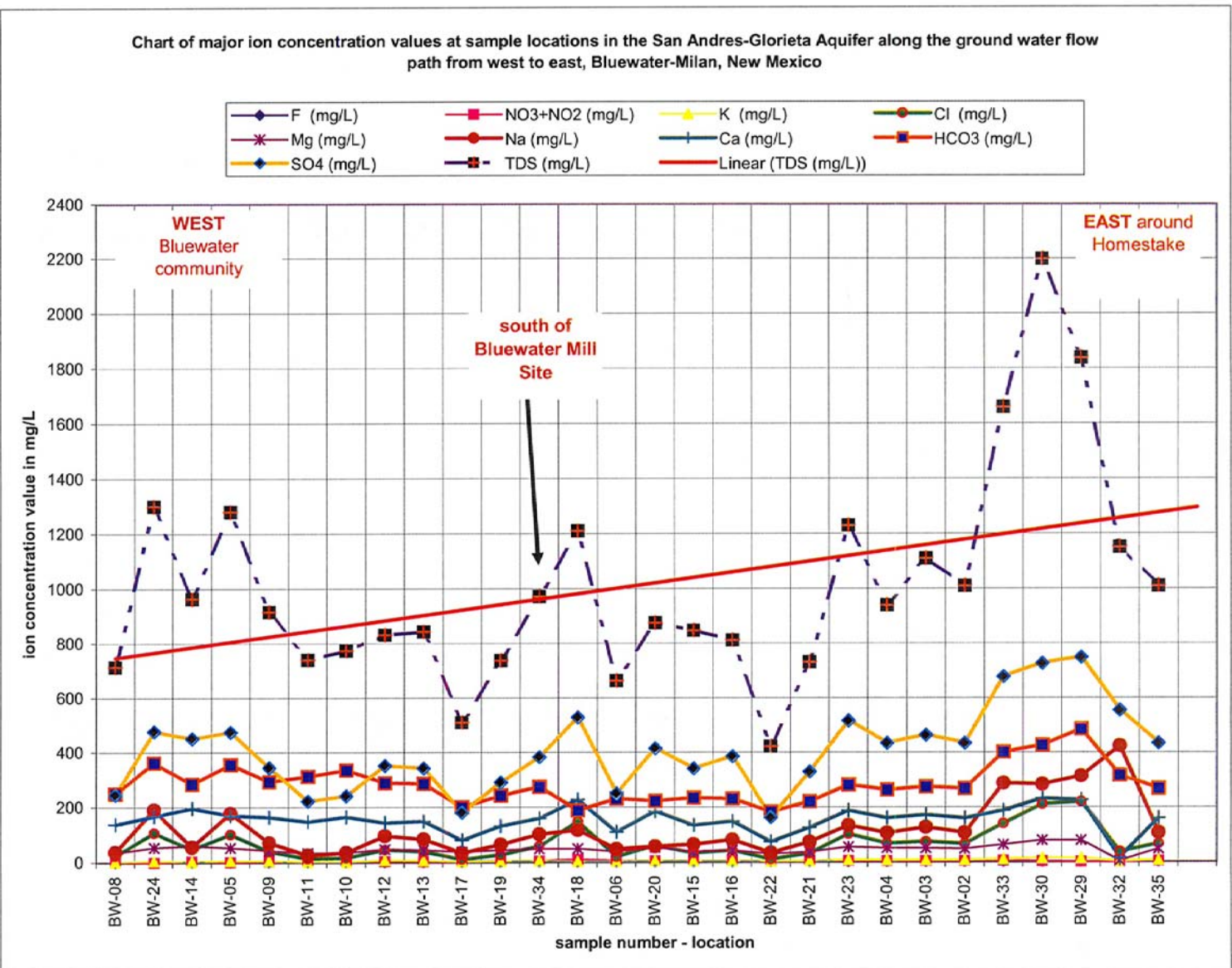
Figure 13. Map of Stiff diagrams for major ion concentrations (2008) in milliequivalents per liter (meq/l) for ground water samples, Bluewater area, New Mexico.
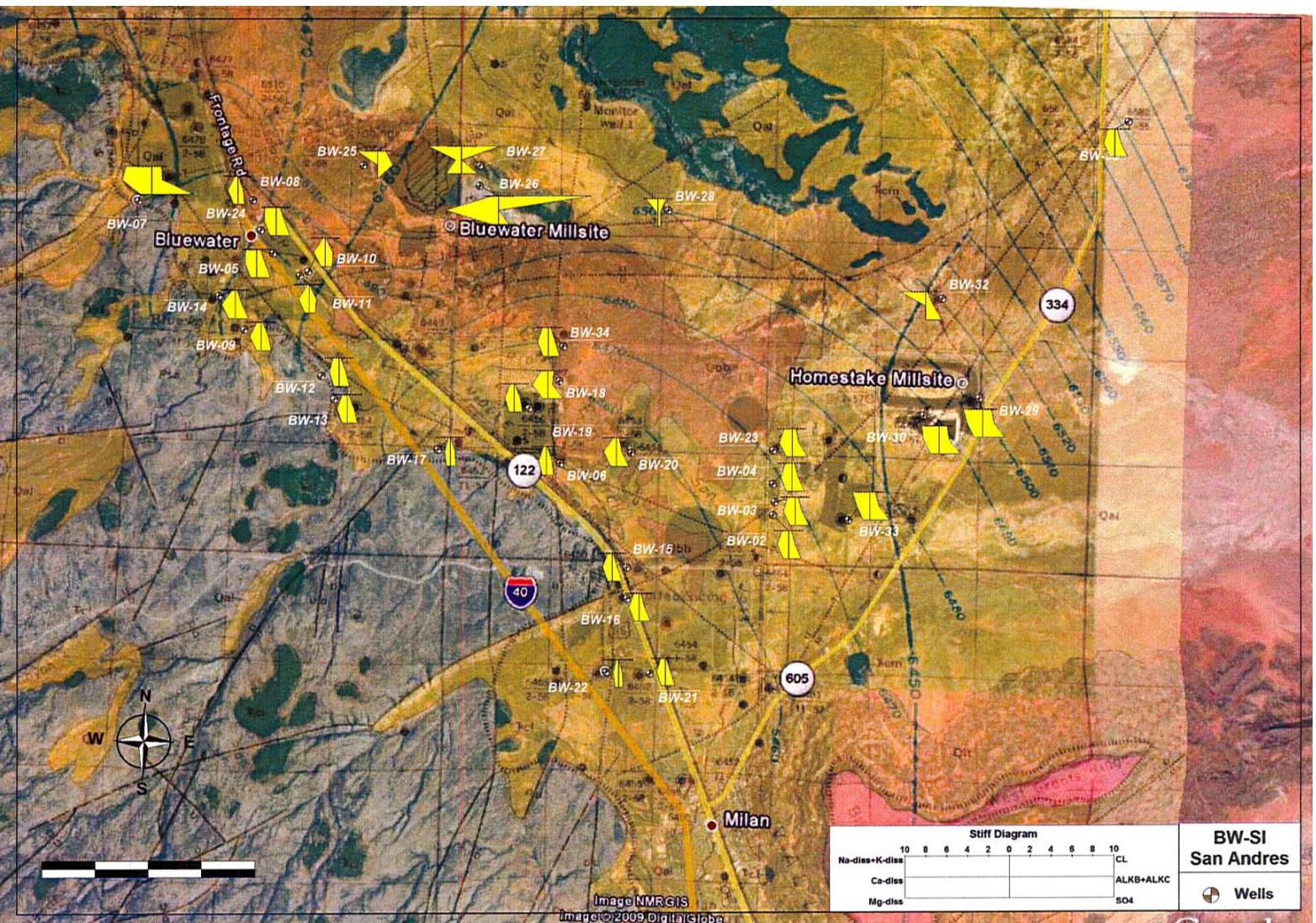
Figure 14. Trilinear (Piper) diagram of the relative percent of major ion concentrations (2008) in milliequivalents per liter (meq/l) for ground water samples, Bluewater area, New Mexico.

Chloride (Cl) versus sulfate (SO4) in mg/L for ground water samples in the SAGS aquifer w/o Bluewater Mill samples, Bluewater-Milan area, New Mexico
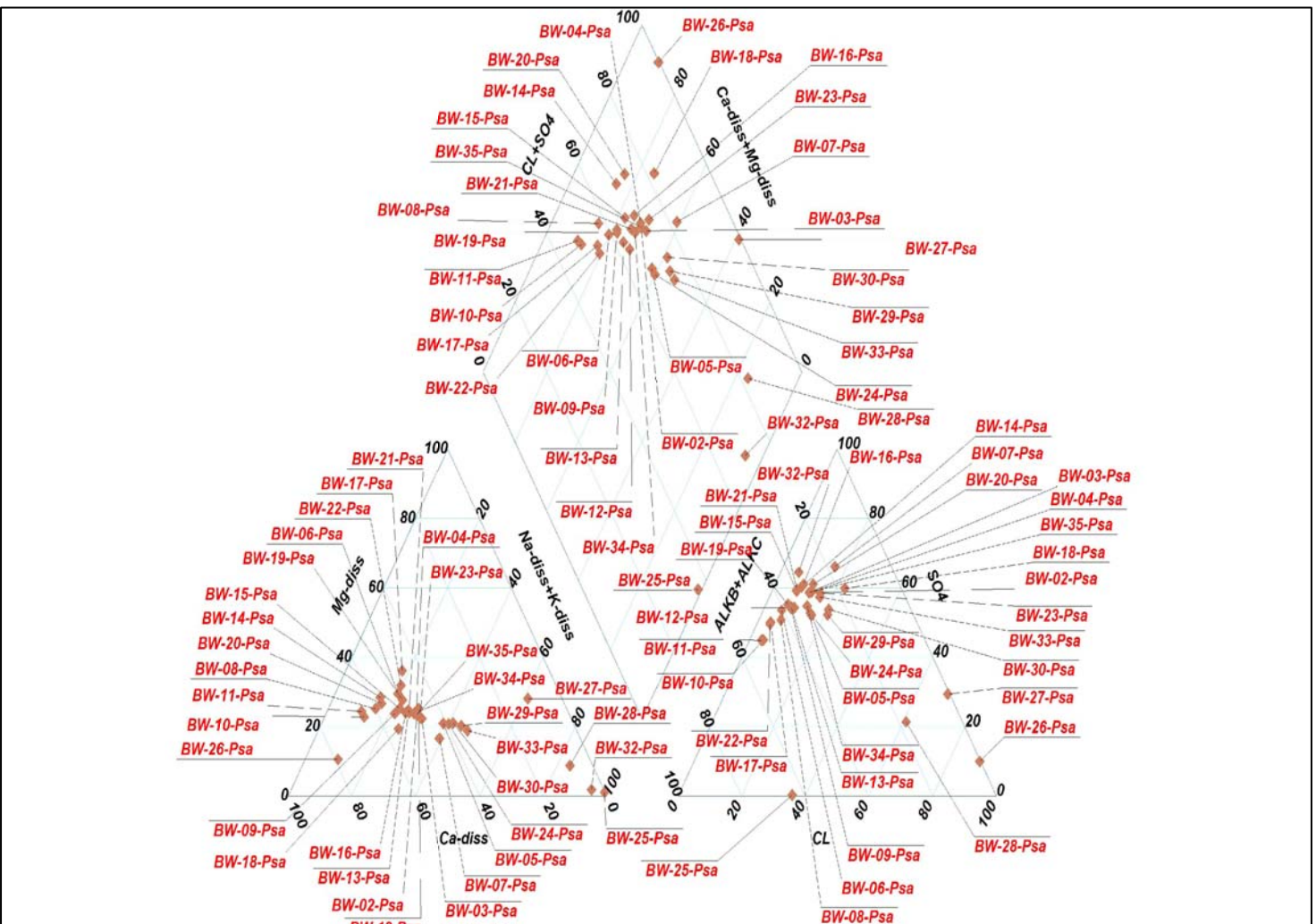
Figure 15. X-Y chart of Cl vs. SO_4 concentrations (2008) in mg/l with a trend line for ground water samples, Bluewater area, New Mexico.
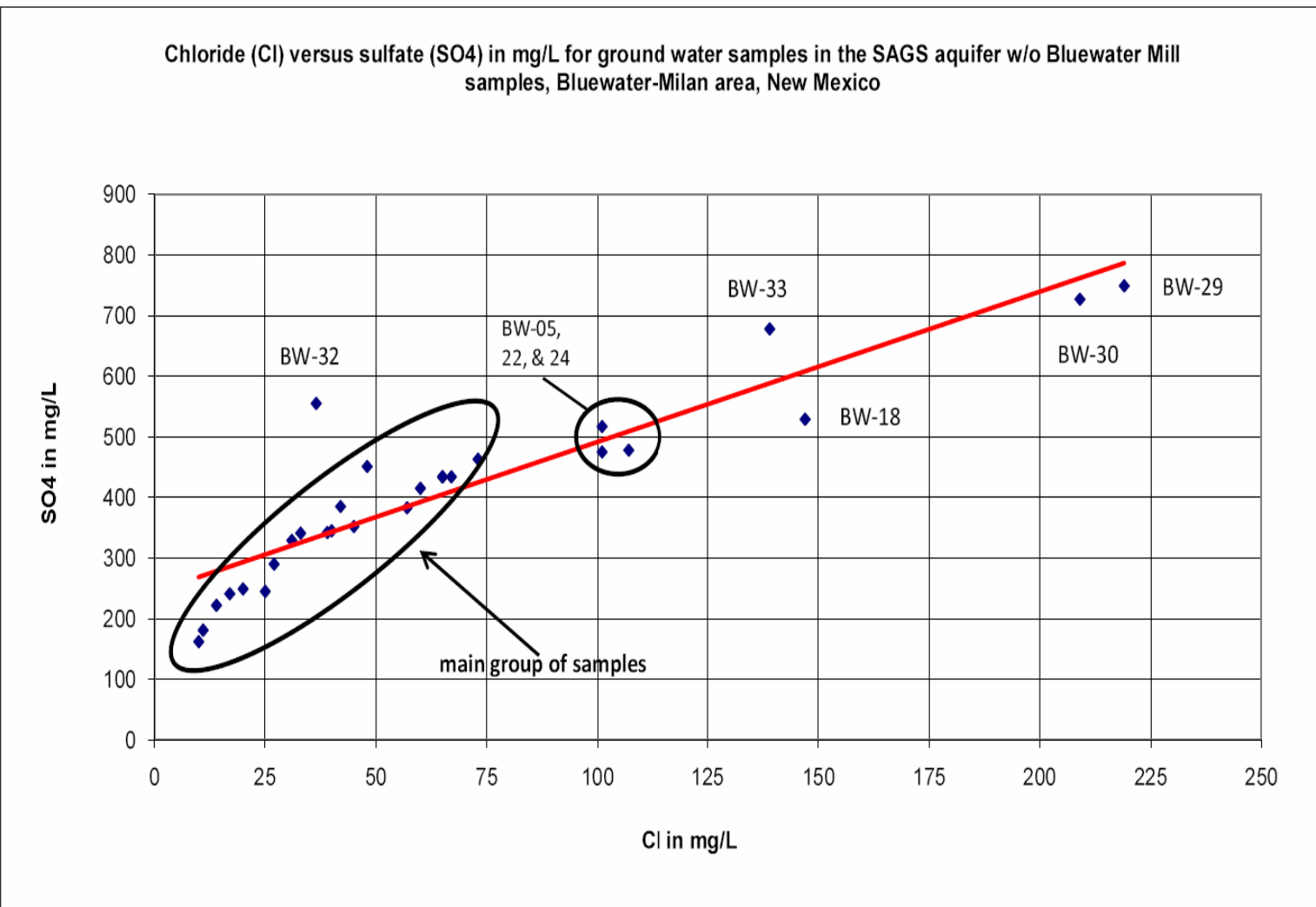
Figure 16. Chart of five trace element concentration (2008) in ug/l for sample locations along the assumed ground water flow path from west to east, Bluewater area, New Mexico.
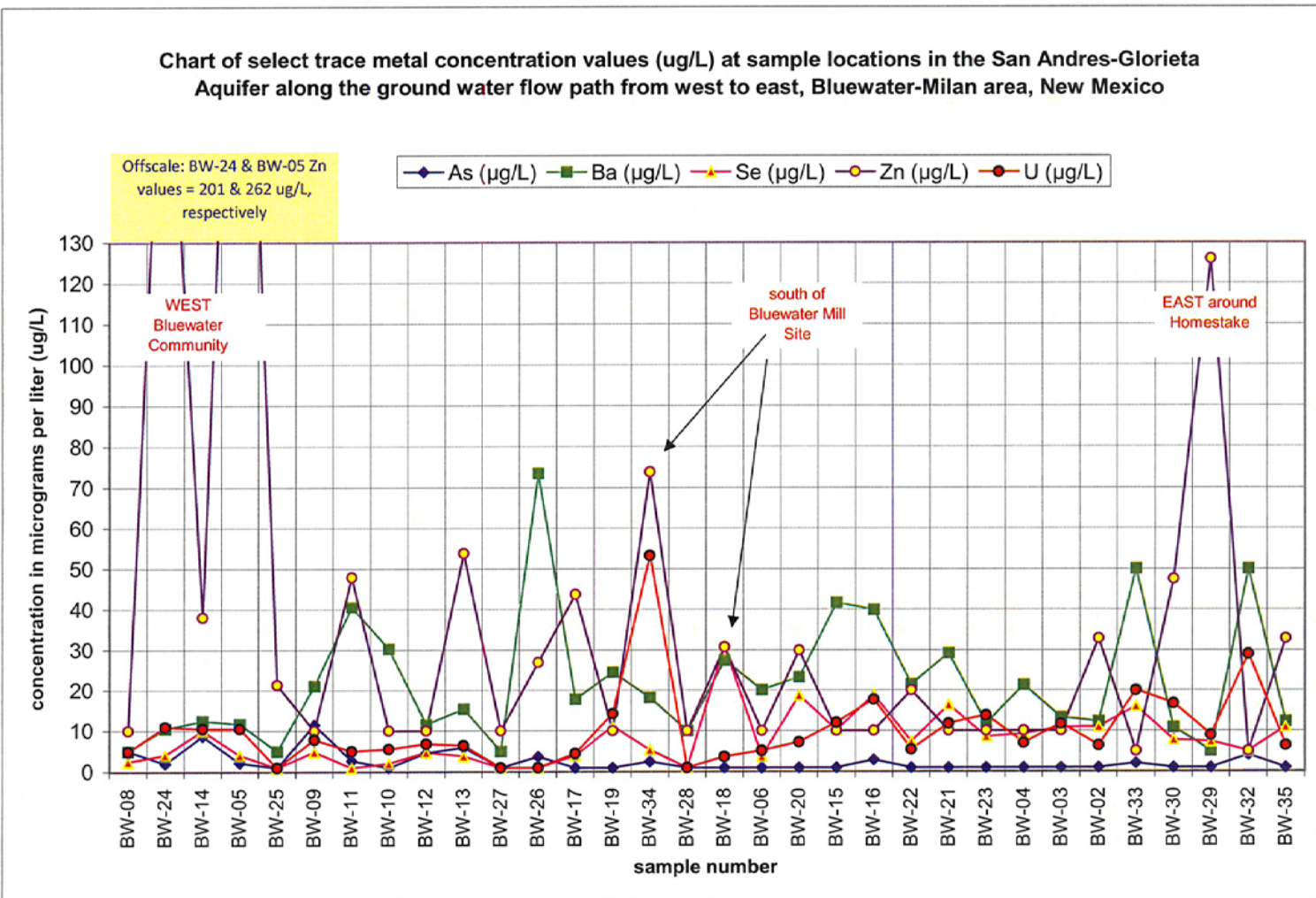
Figure 17. Location map of dissolved uranium concentrations (2008) in ug/l at ground water sample locations, Bluewater area, New Mexico.
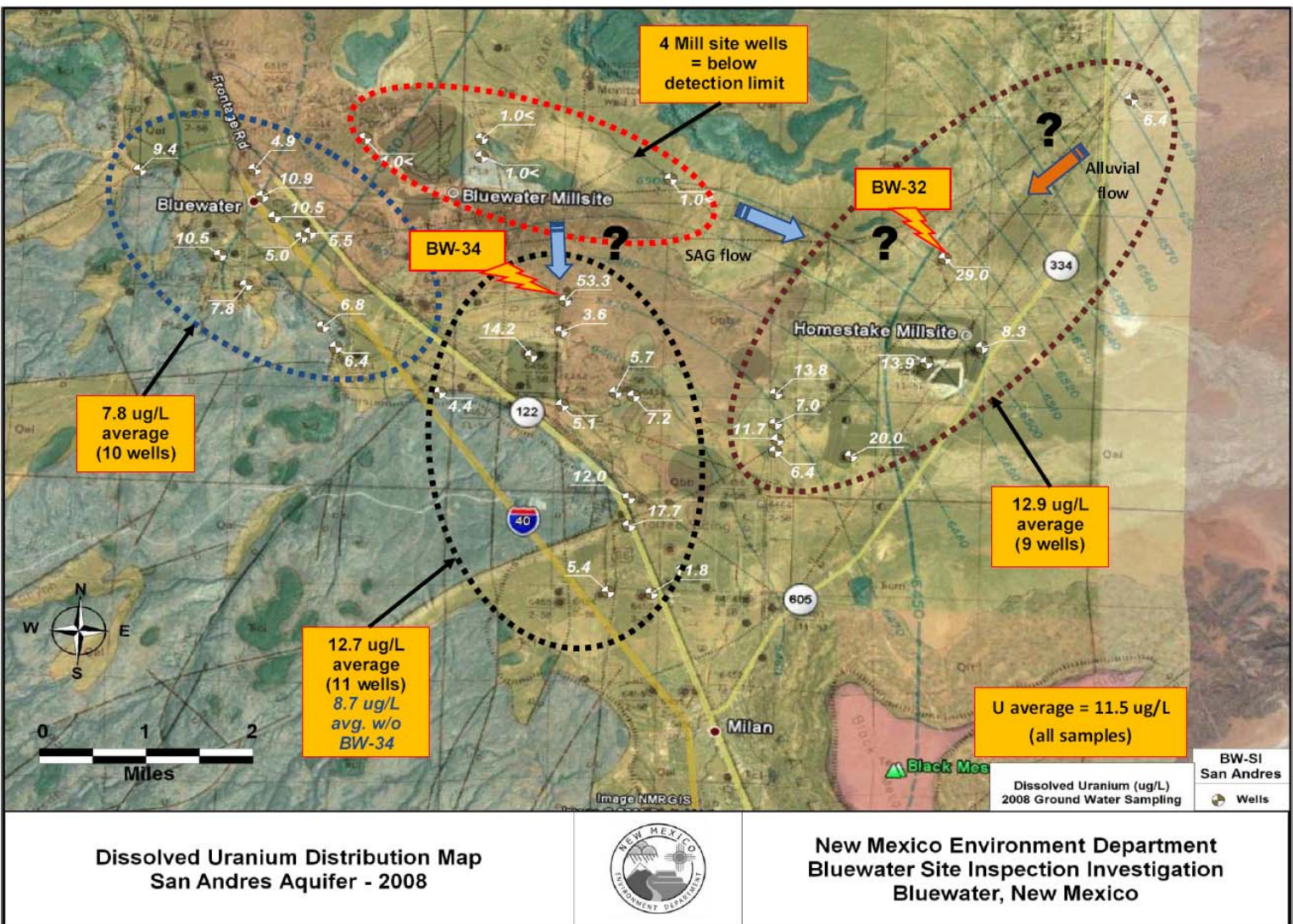
Figure 18. Chart of radium isotope concentrations (2008) in picocuries per liter (pCi/l) for sample locations along the assumed ground water flow path from west to east, Bluewater area, New Mexico.
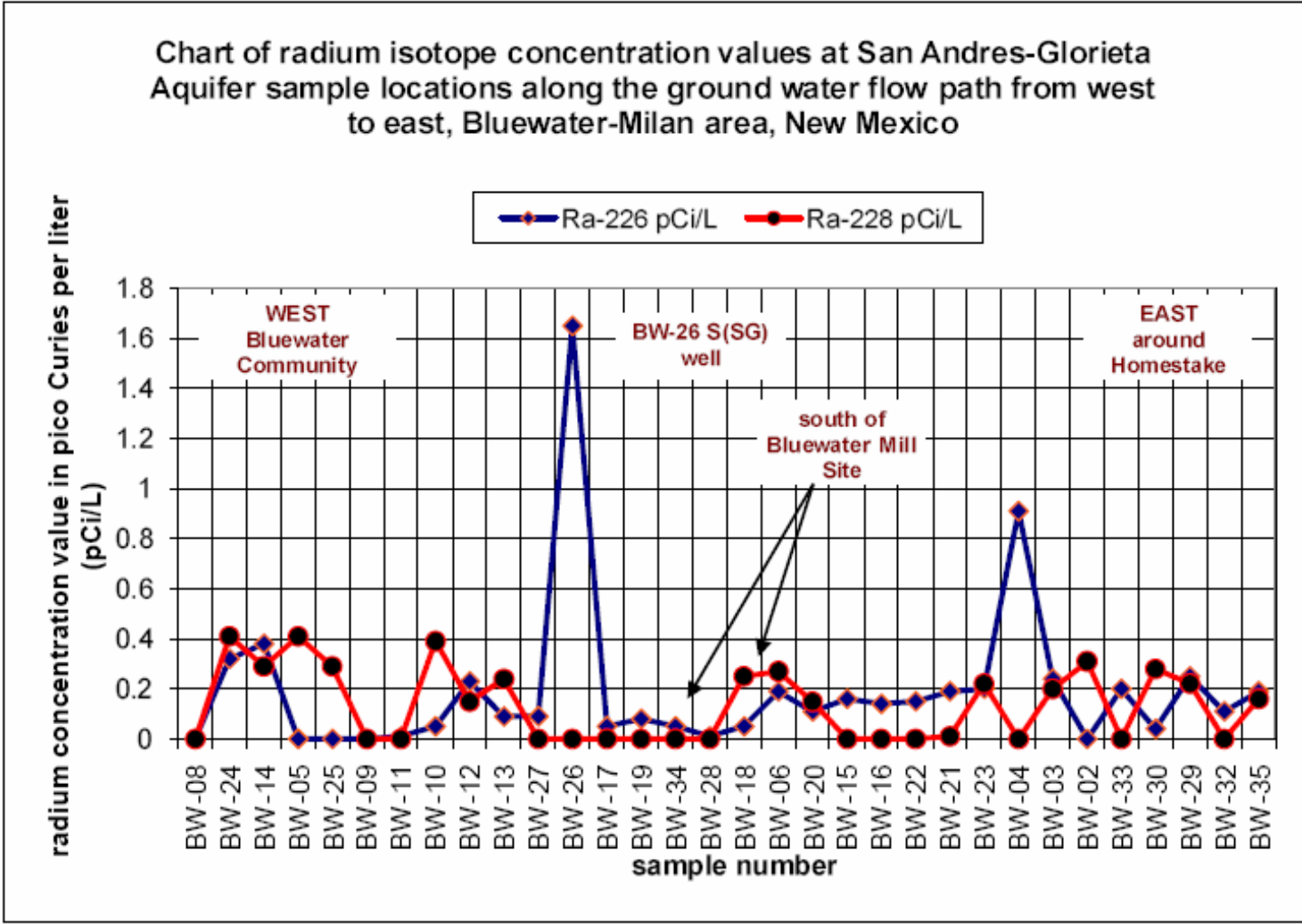
Figure 19. Relation of ^{234}U: ^{238}U alpha activity ration to the reciprocal of uranium concentration for raffinate control samples and samples of alluvial ground water, uranium mill site, southwestern Colorado. Samples additionally coded according to their molybdenum concentrations (after Zielinski et al, 1997).
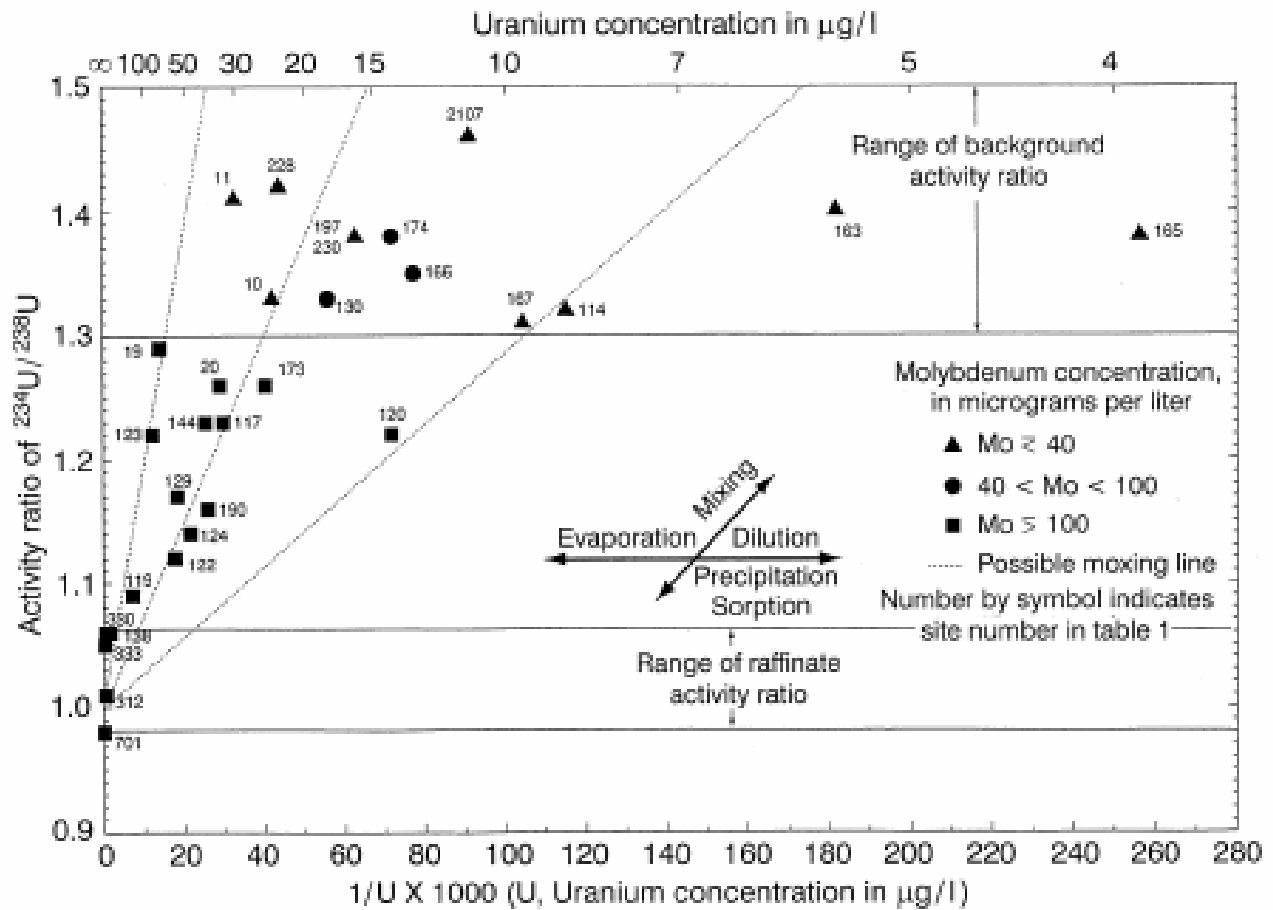
Figure 20. X-Y chart of the^{234}U: ^{238}U activity ration vs. uranium concentrations (2008) in ug/l for a select set of ground water sample locations, Bluewater area, New Mexico.
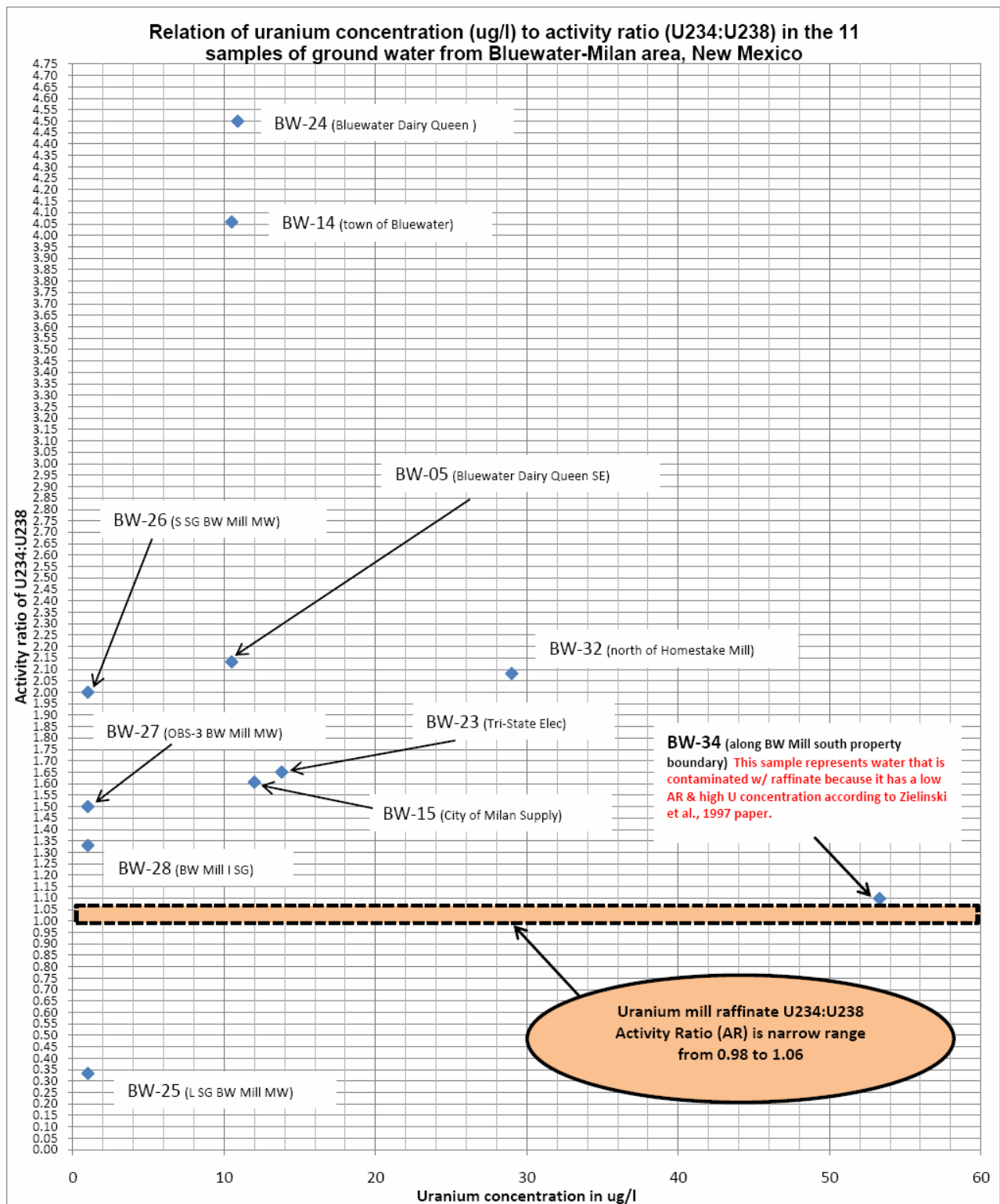
Figure 21. X-Y chart of the stable isotope values (2008) of $\delta^{18}O$ vs. δD (o/oo) for a select set of ground water samples, Bluewater area, plotted with the Craig meteoric water line and the local meteoric water line for the Albuquerque area, Bluewater-Milan area, New Mexico.
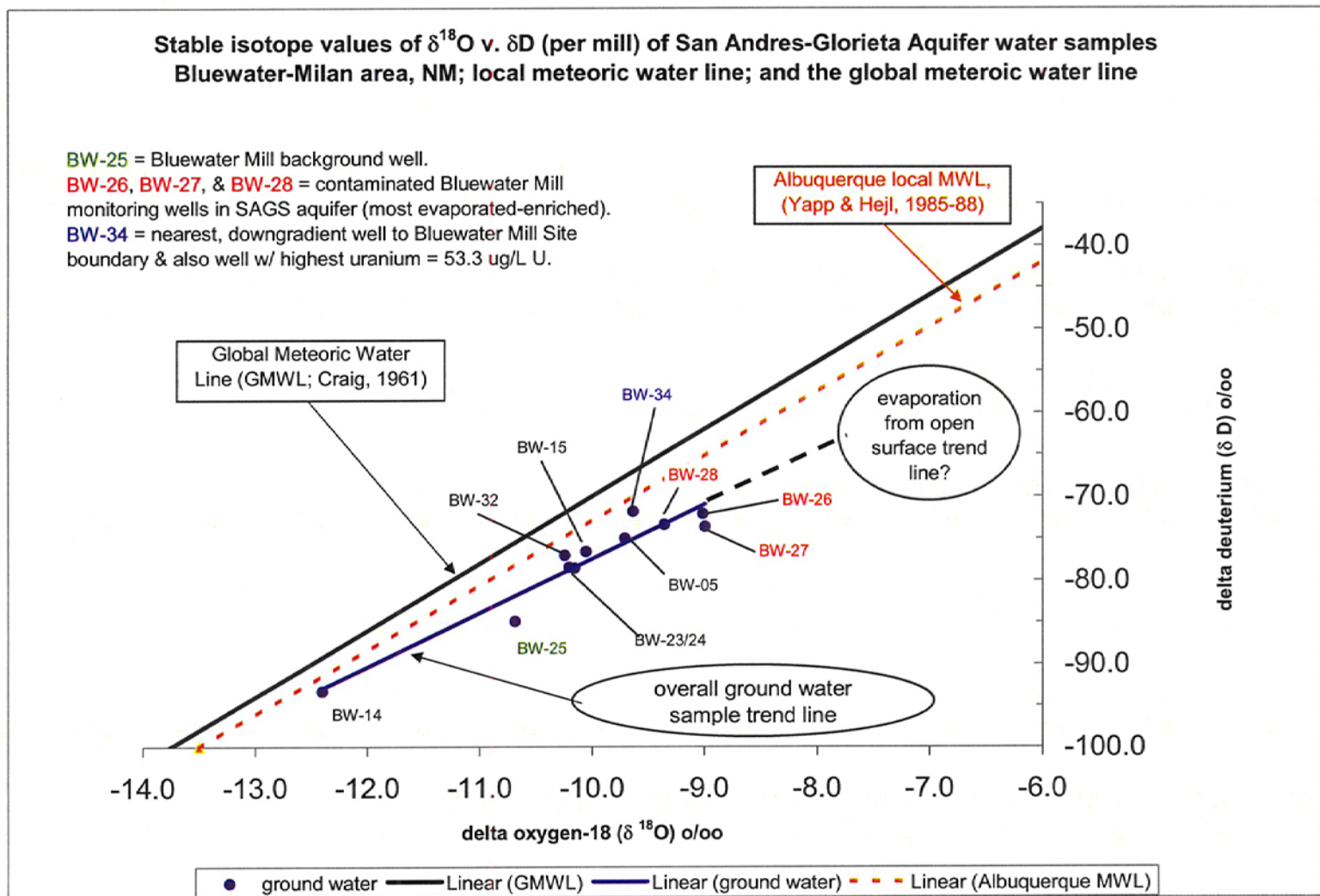
Figure 22. Range of $\delta^{13}C$ isotope values (o/oo) in different types of carbonate reservoirs and the range of $\delta^{13}C$ isotope values (2008) for a select set of ground water samples, Bluewater area, New Mexico (after Eby, 2004).

Figure 6-9. Range of $\delta^{13}C$ values for different carbon reservoirs.

Sulfate (SO$_4$) in mg/L versus δ^{34}S (o/oo), for ground water samples in the SAGS aquifer, Bluewater-Milan set of samples
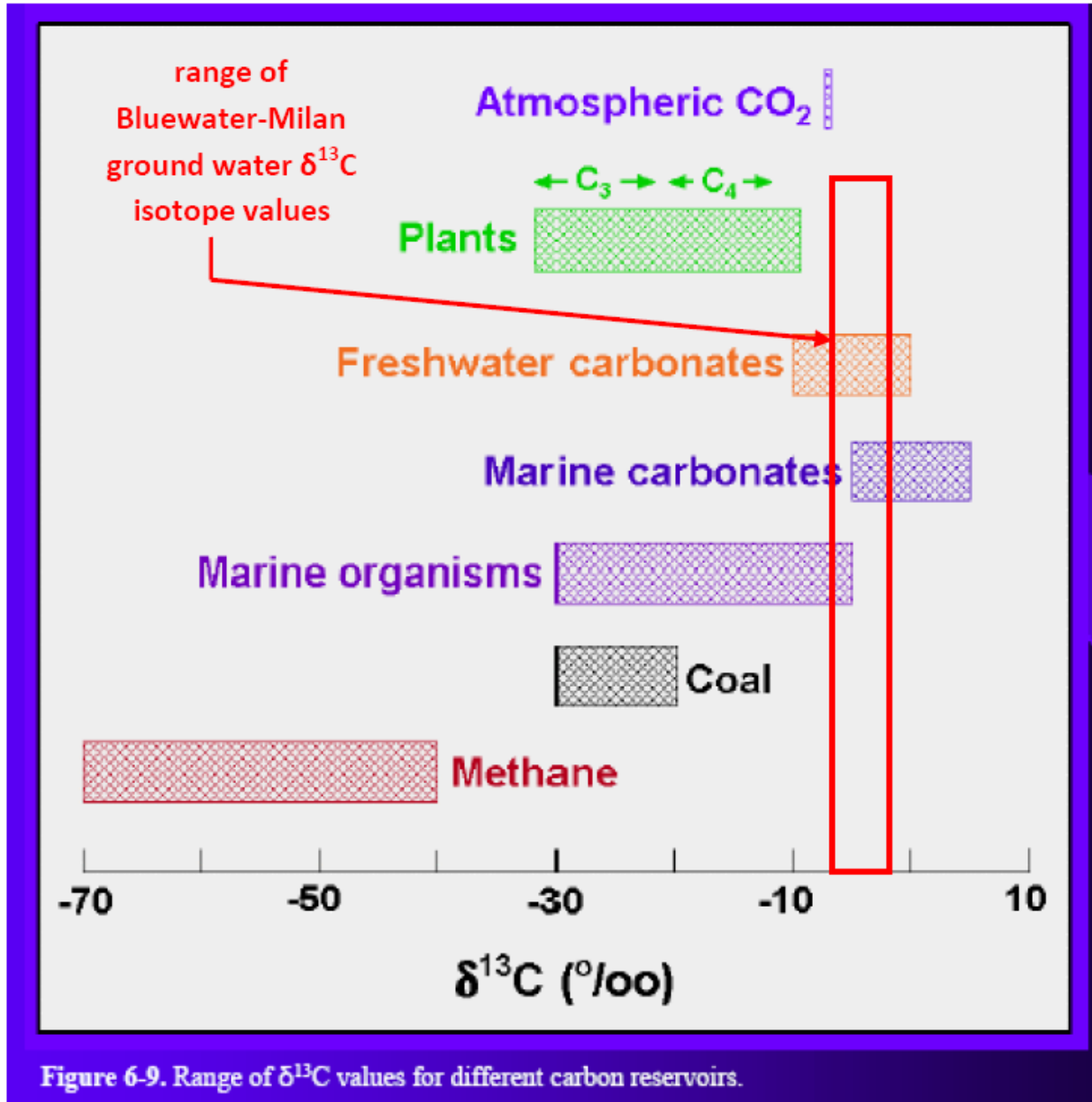
Figure 23. X-Y chart of SO$_4$ concentration in mg/l vs. isotope values (2008) in o/oo for a select set of ground water samples, Bluewater area, New Mexico.
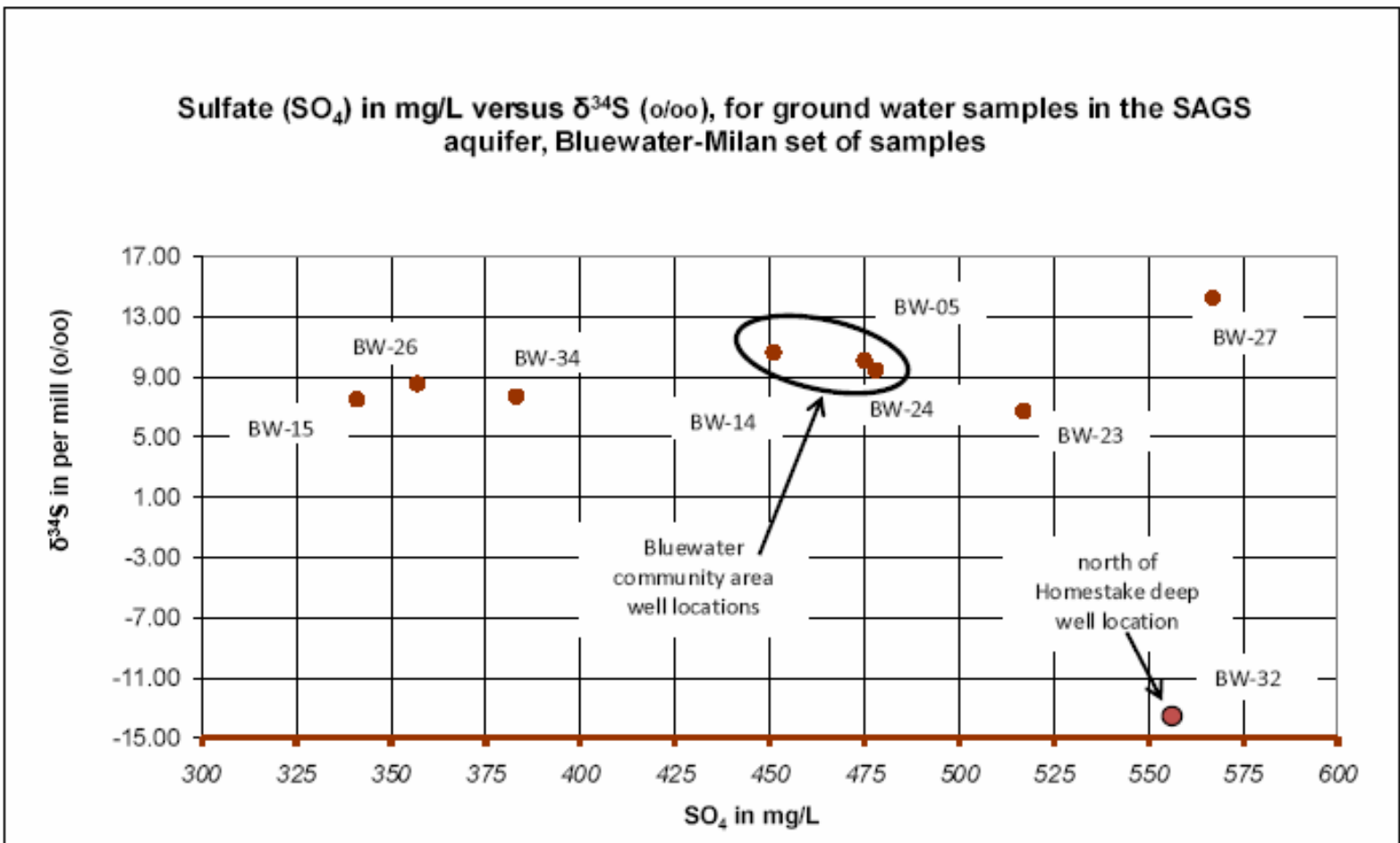
Figure 24. Comparison of biogenic and hydrothermal $\delta^{34}S$ sulfur isotope values(o/oo) from various uranium ore deposits in the western United States and Grants Mineral Belt (after Jensen, 1963). For comparison the range of $\delta^{34}S$ values for the Bluewater-Milan ground water samples are shown in the red area and the $\delta^{34}S$ value of sample BW-32 is shown as the dashed blue line (after Jensen, 1963).
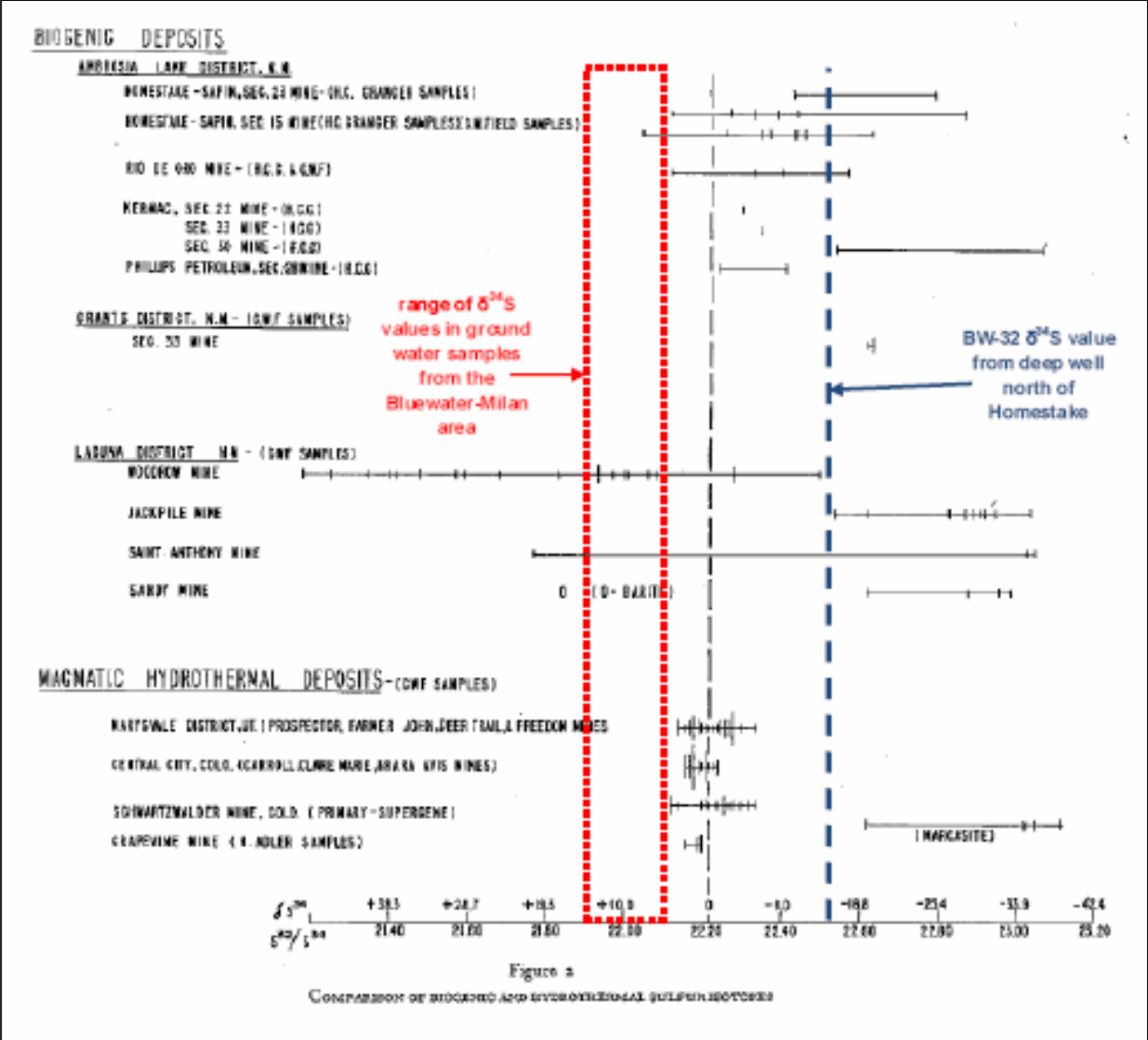
Figure 25. Map of ground water sample locations in the San Mateo Creek area, New Mexico.

Major ion concentrations at Qal sample locations along the assumed ground water flow path from north to south, San Mateo Creek, New Mexico
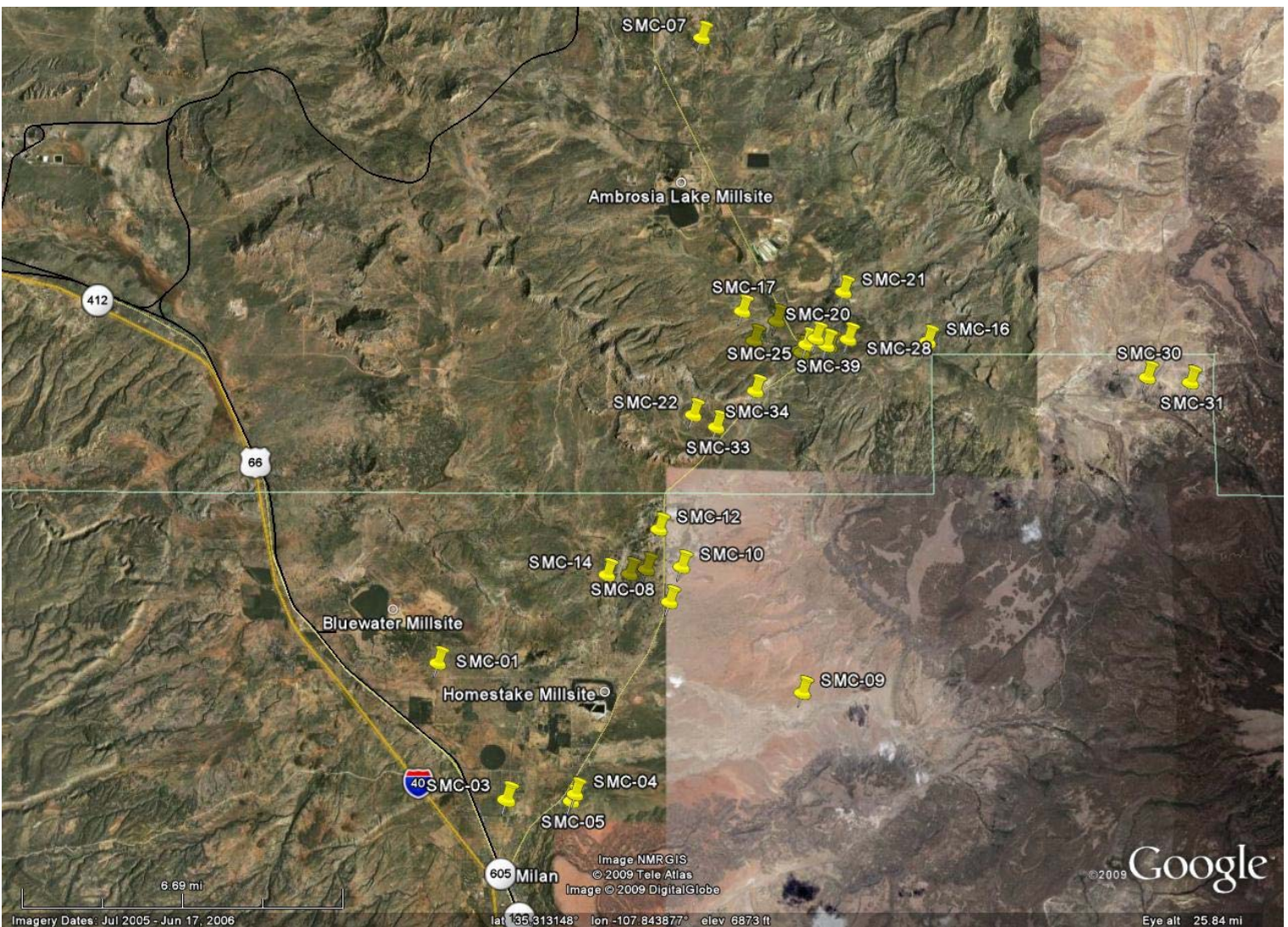
Figure 26. Chart of major ion and TDS concentrations (2009) in mg/l at sample locations in the alluvial aquifer along the assumed ground water flow path from north to south, San Mateo Creek area, New Mexico.
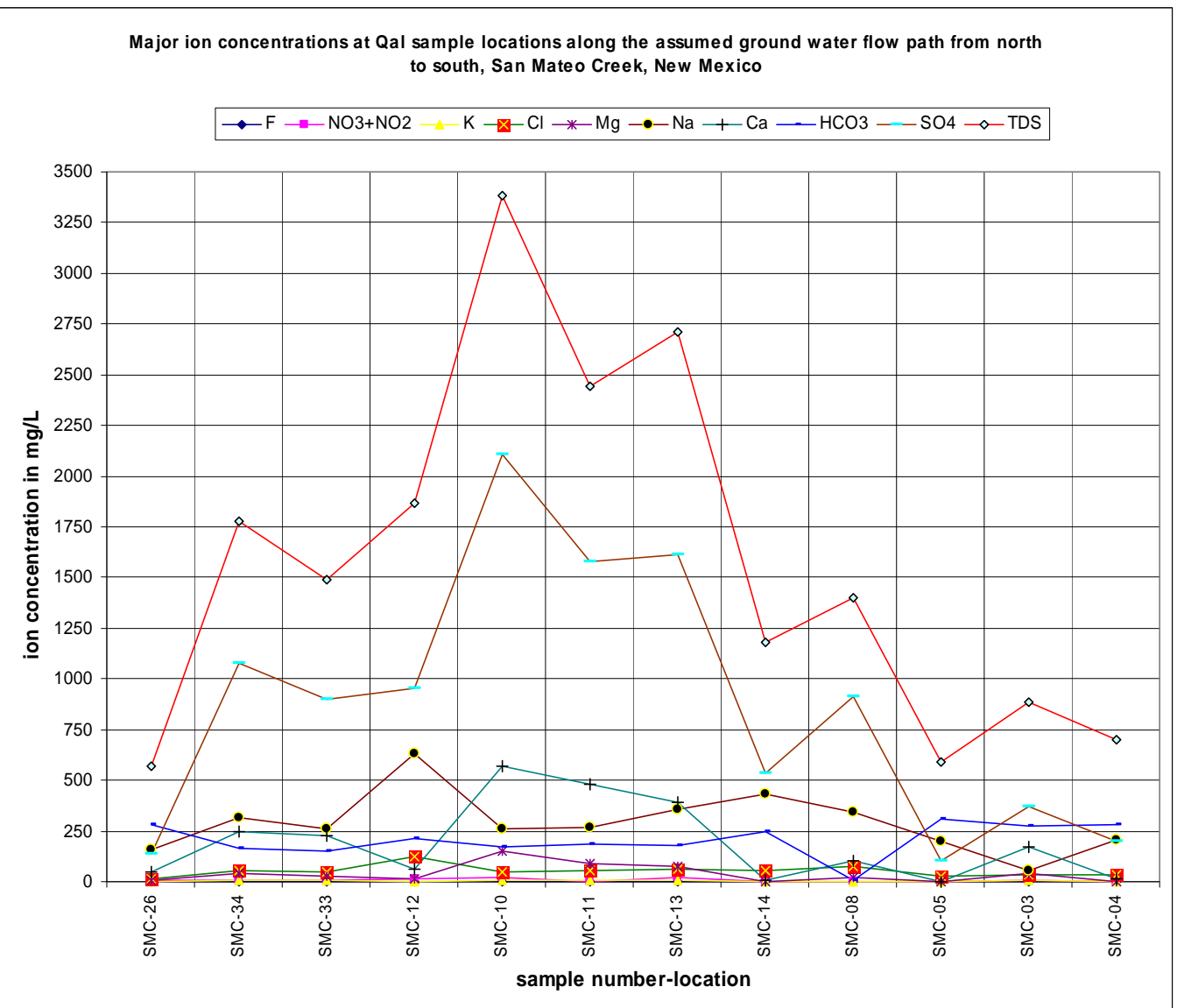
Figure 27. Chart of major ion and TDS concentrations (2009) in mg/l at sample locations in the Jurassic Morrison Formation (Westwater Canyon member) and other bedrock units along the assumed ground water flow path from north to south, San Mateo Creek area, New Mexico.
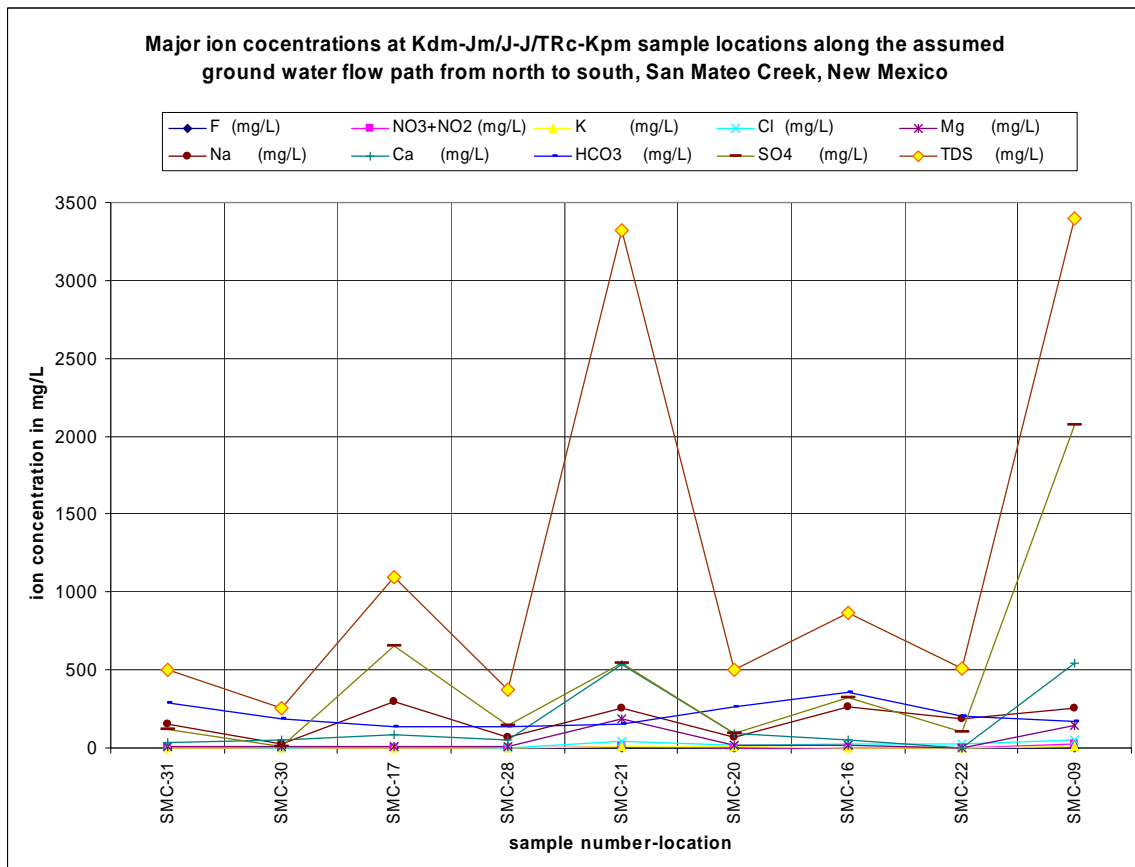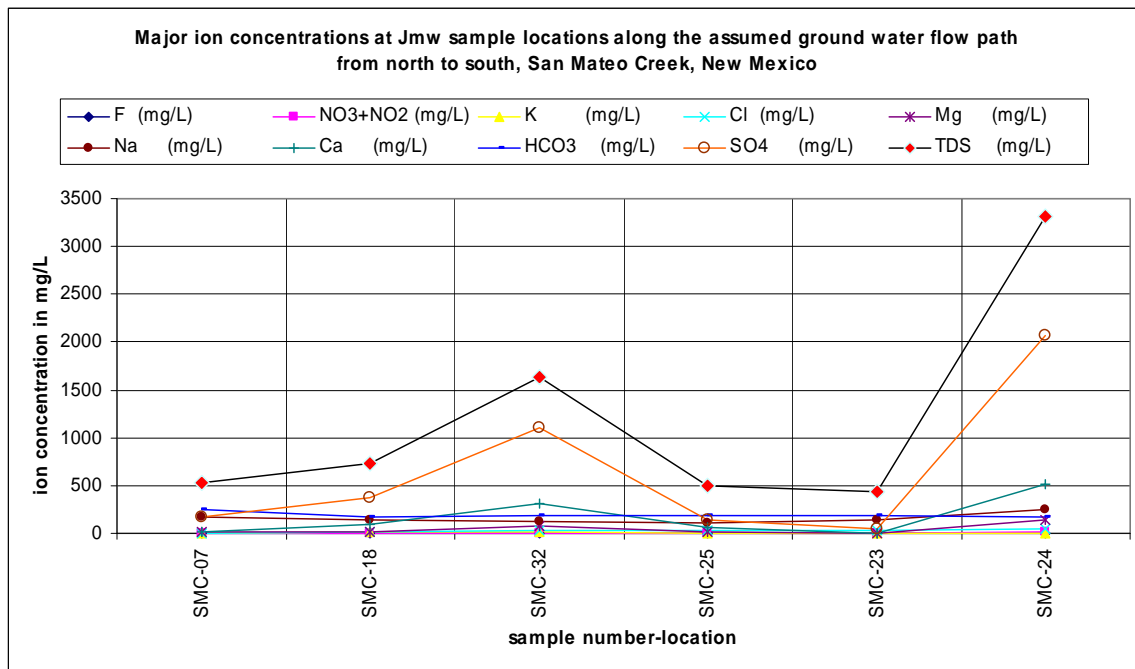
Figure 28. Map of Stiff diagrams for major ion concentrations (2009) in milliequivalents per liter (meq/*l*) at ground water sample locations, San Mateo Creek area, New Mexico.
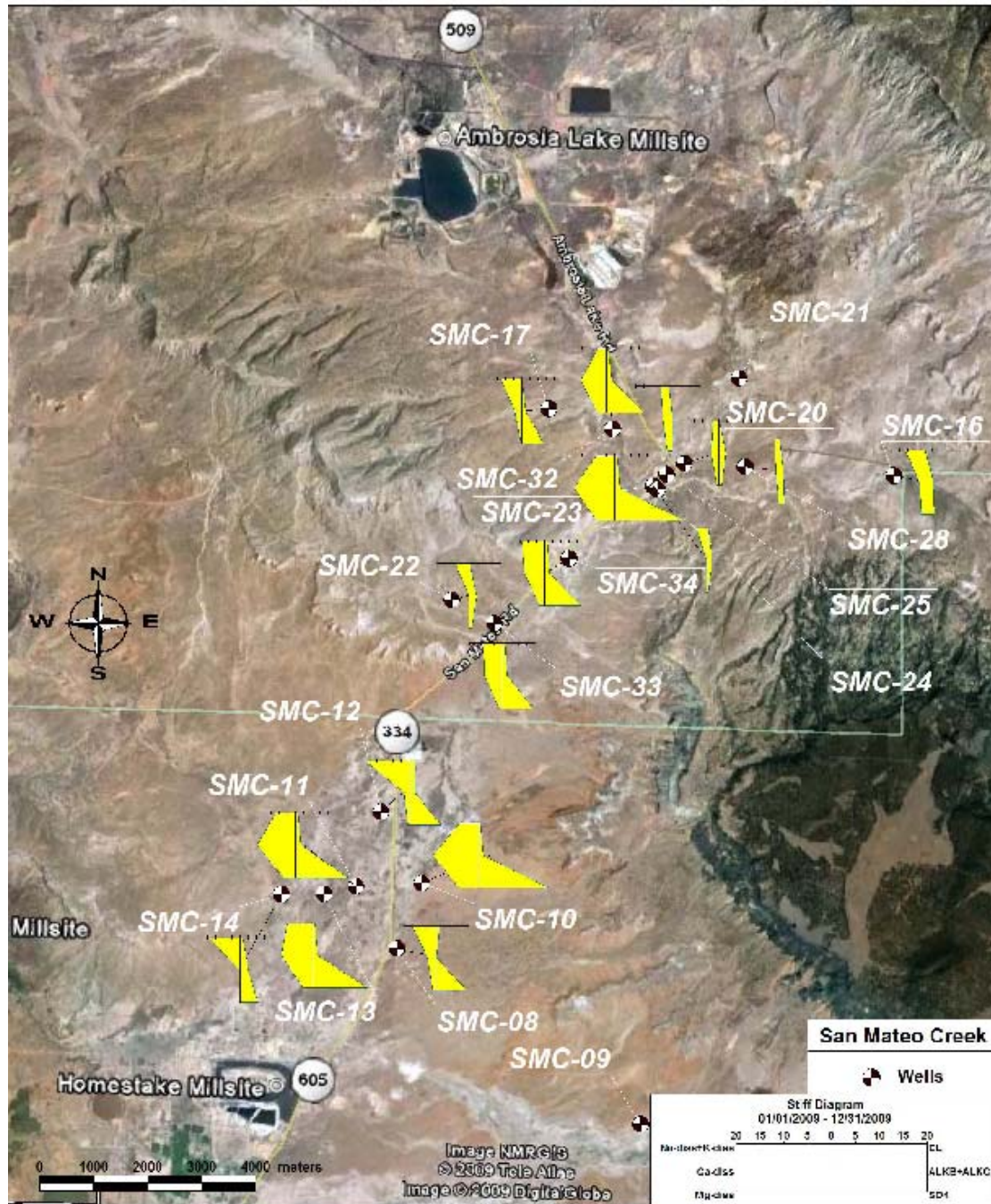
Figure 29. Trilinear (Piper) diagram of the relative percentage of major ion concentrations (2009) in meq/l for ground water samples from the alluvial aquifer, San Mateo Creek area, New Mexico.
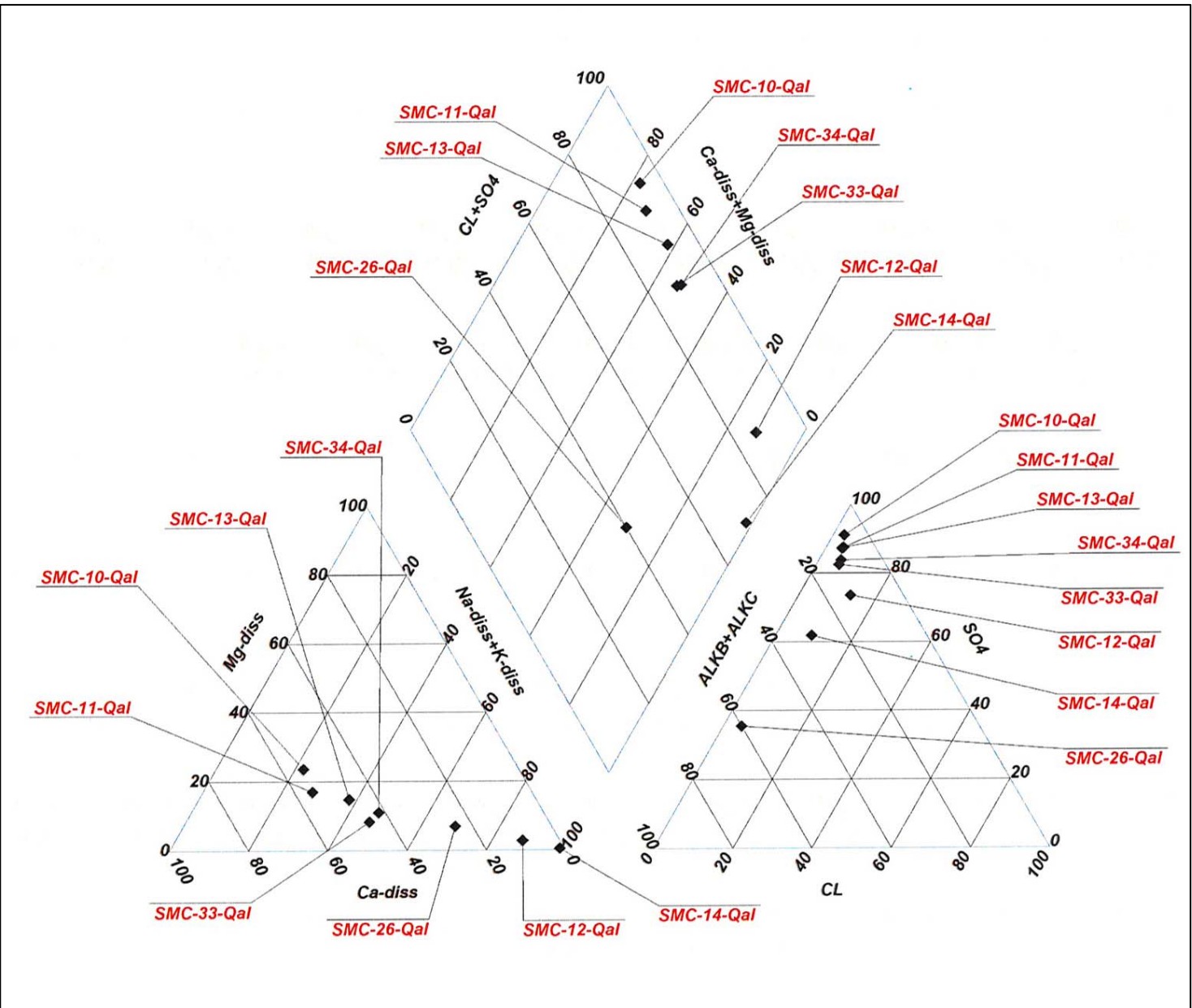
Figure 30. Trilinear (Piper) diagram of the relative percentage of major ion concentrations (2009) in meq/l for ground water samples from the Jurassic Morrison Formation (Westwater Canyon Member), San Mateo Creek area, New Mexico.
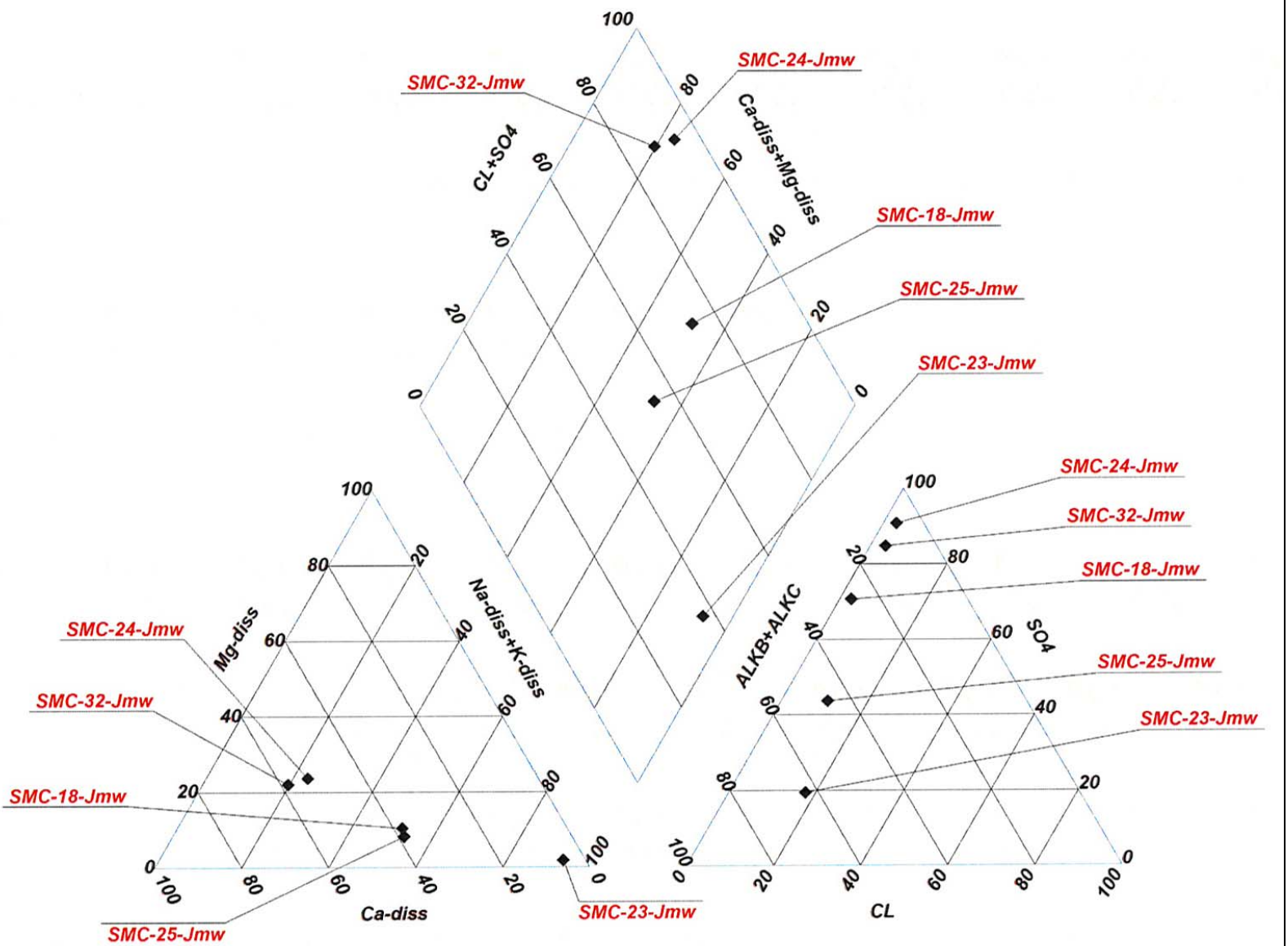
Figure 31. Trilinear diagram from Brod (1979) showing average ion compositions in relative percent meq/l for aquifer units, San Mateo Creek area, New Mexico.
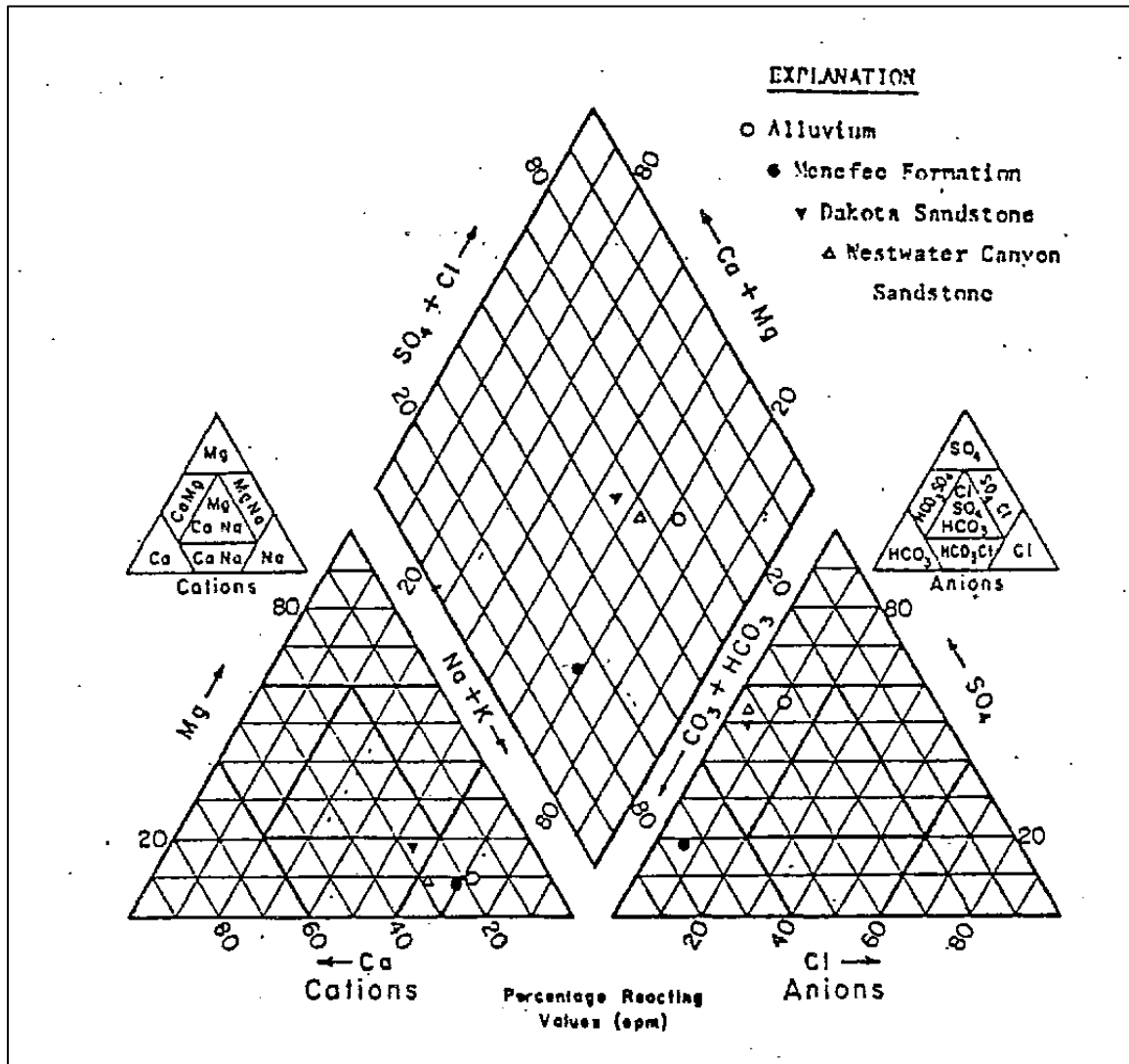
Figure 32. Chart of seven trace element concentrations (2009) in ug/l for sample locations along the assumed ground water flow path from north to south, San Mateo Creek area, New Mexico.
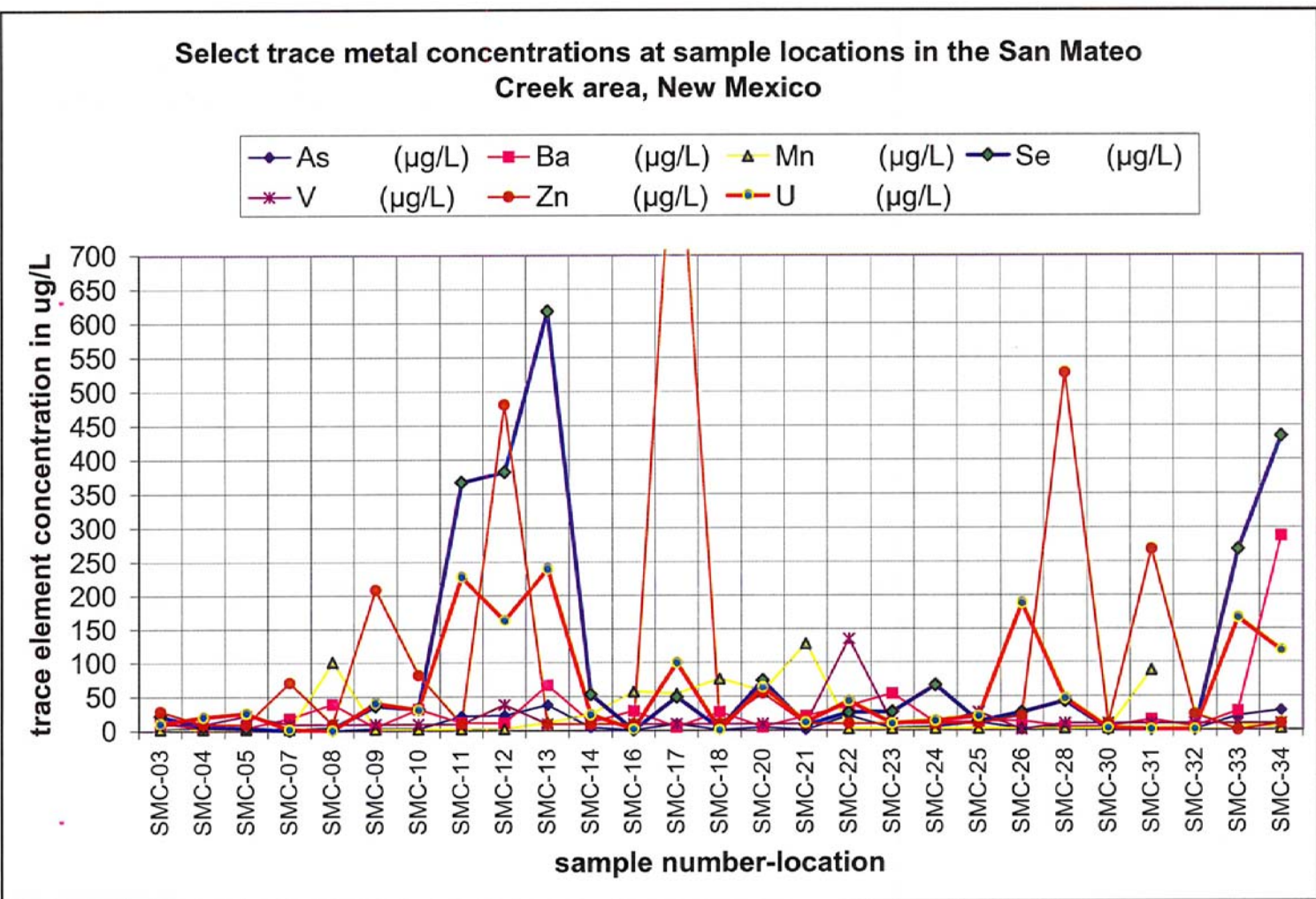
Figure 33. Location map of dissolved uranium concentrations (2009) in ug/l at ground water sample locations, San Mateo Creek area, New Mexico.

Plot of U concentration vs. Se concentration in ug/L for San Mateo Creek samples, New Mexico

Figure 34. X-Y chart of U vs. Se concentrations (2009) in ug/l for ground water sample locations, San Mateo Creek area, New Mexico.
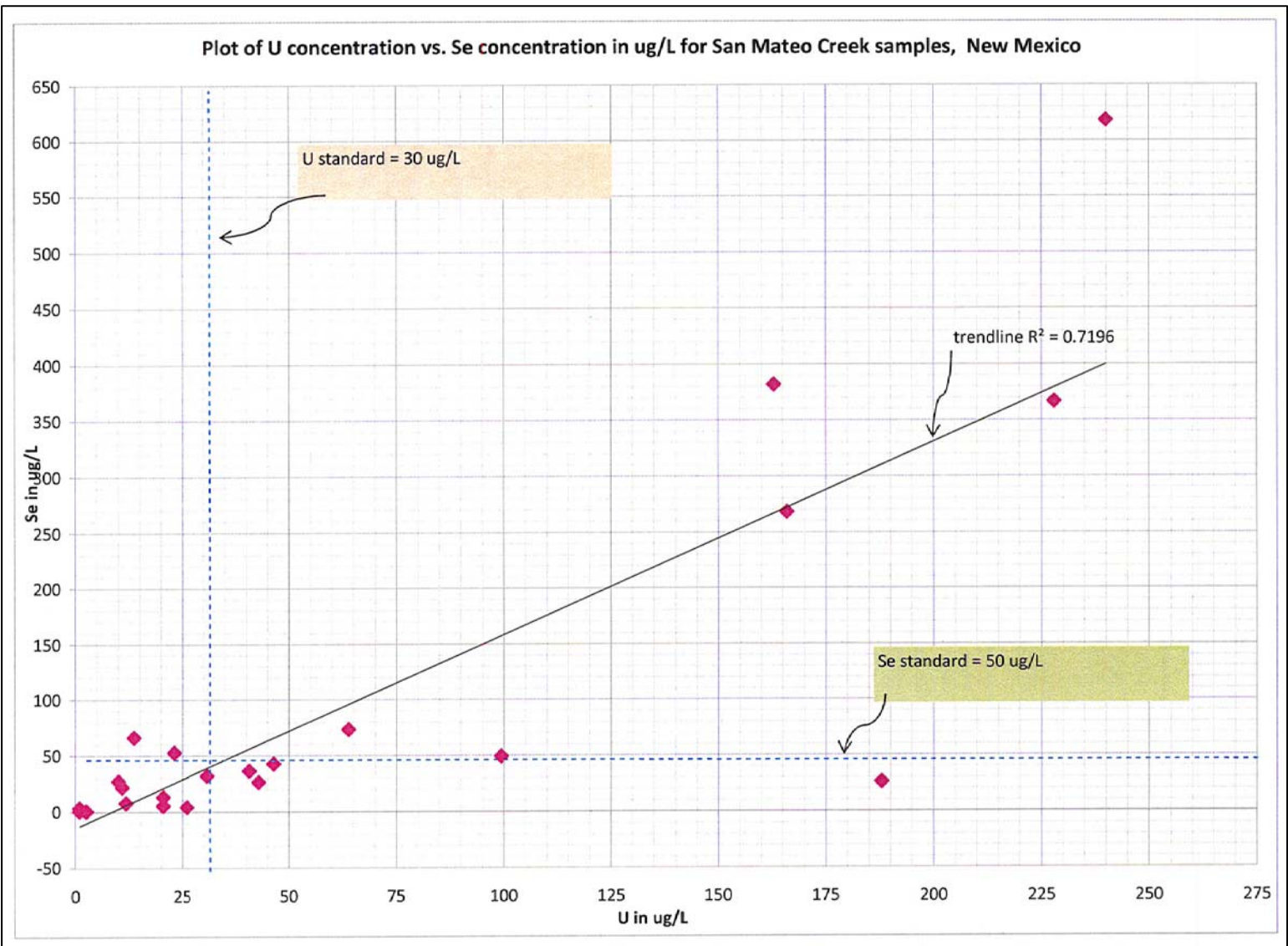
Figure 35. X-Y chart of the ^{234}U:^{238}U activity ratio vs. uranium concentrations (2009) in ug/l for a select set of ground water sample locations, San Mateo Creek area, New Mexico.

Relation of uranium (ug/l) to U234:U238 activity ratio in the 19 samples of ground water from the San Mateo Creek area, New Mexico

SMC-11, -12, and -13 have a U = 228, 163, & 240 ug/l, respectively. SMC-11, -12, and -13 have a Se = 367, 382, & 618 ug/l, respectively. These high values and low AR suggest these samples are contaminated with U mill raffinate.

range of raffinate activity ratio (0.98-1.06) from Zielinski et al., 1997)

1/U X 1000 (U, uranium concentration in ug/l)

Activity ratio of U234:U238
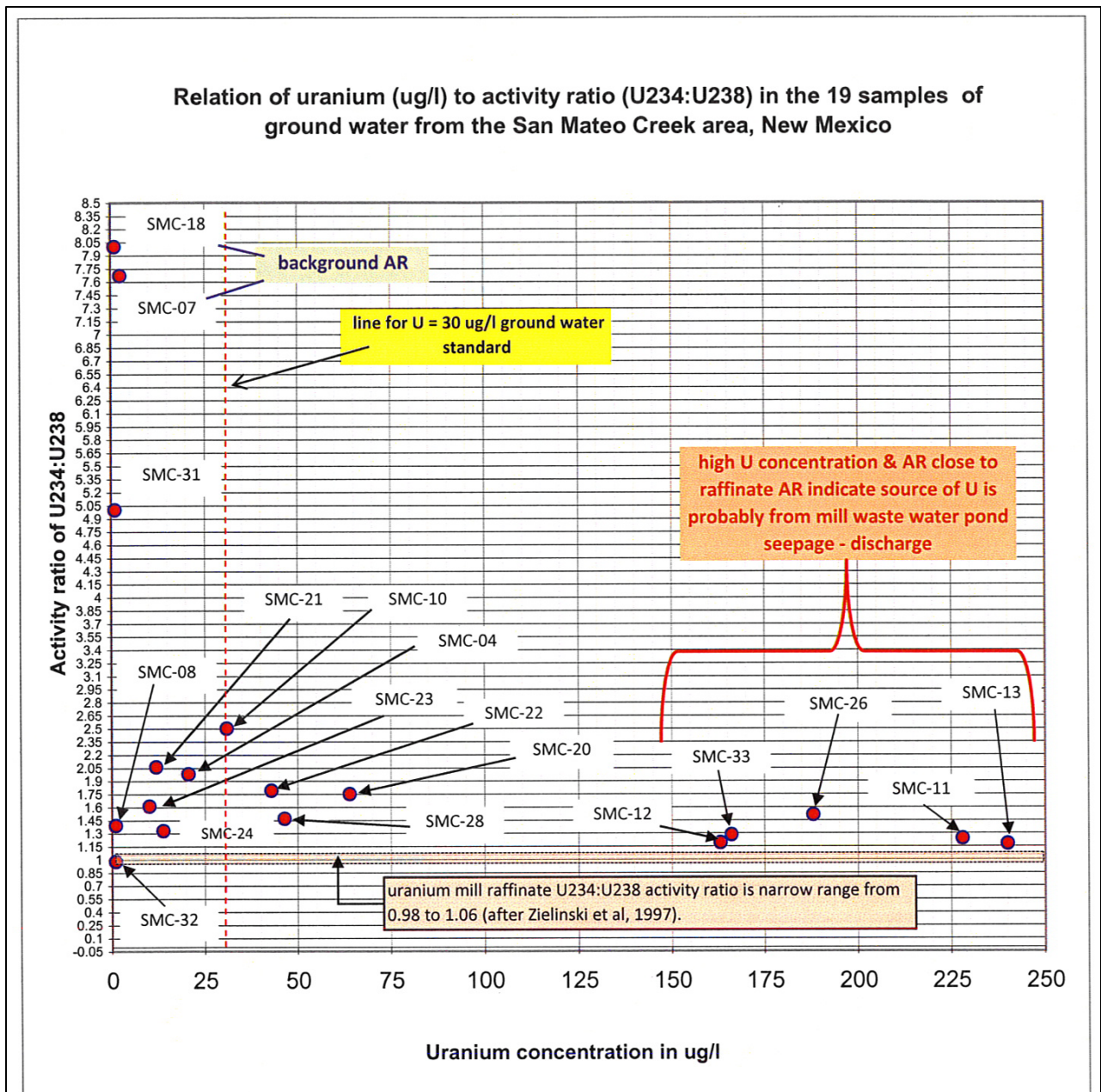
Figure 36. X-Y chart of the ^{234}U:^{238}U activity ratio vs. the reciprocal of uranium concentrations (2009) in ug/l for a select set of ground water sample locations, San Mateo Creek area, New Mexico (after Zielinski, 1997).

Stable isotope values of δ^{18}O vs. δD (o/oo) of ground water samples, San Mateo Creek area, New Mexico

Ground Water   GMWL

samples SMC-11 & SMC-35 = duplicate
samples SMC-26 & SMC-36 = duplicate
red labels = high U concentration 163 - 240 ug/L

more enriched

SMC-08

SMC-10

SMC-28   SMC-39
          SMC-26   SMC-36
SMC-21   SMC-23
          SMC-24
SMC-20
          SMC-32   SMC-12
SMC-18   SMC-35   SMC-13
          SMC-11
SMC-33

Global Meteoric Water Line

more depleted

SMC-31

higher elevation
sample locations

SMC-07

δ^{18}O o/oo

δD o/oo

Figure 37. X-Y chart of the stable isotope values of δ^{18}O vs. δD (2009) in per mil (o/oo) for a select set of ground water samples, plotted with the Craig meteoric water line, San Mateo Creek area, New Mexico.
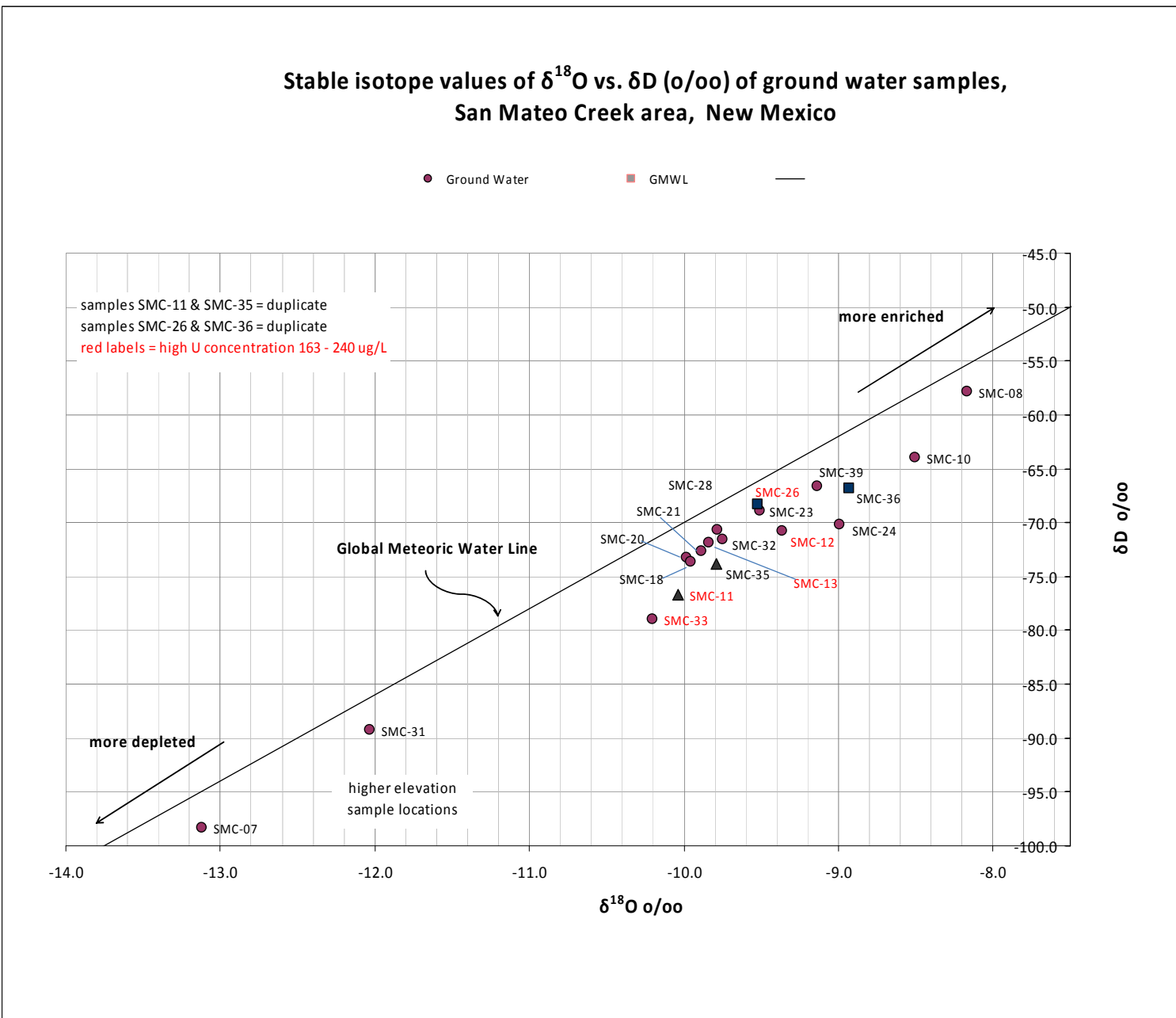
Figure 38. Range of $\delta^{13}C$ values (o/oo) in different carbonate reservoirs and the range of $\delta^{13}C$ values in ground water samples from the San Mateo Creek area, New Mexico (after Eby, 2004).

Figure 6-9. Range of $\delta^{13}C$ values for different carbon reservoirs.

Figure 39. Comparison of biogenic and hydrothermal sulfur isotopes in uranium ore samples and range of $\delta^{34}S$ values in ground water samples from the San Mateo Creek area, New Mexico (after Jensen, 1963).

Figure 40. X-Y chart of SO4 concentration in mg/l vs. δ34S isotope values (2009) in o/oo for ground water samples in the San Mateo Creek area, New Mexico.

Comparison of Major Ion Average Values, Bluewater and San Mateo Creek Samples
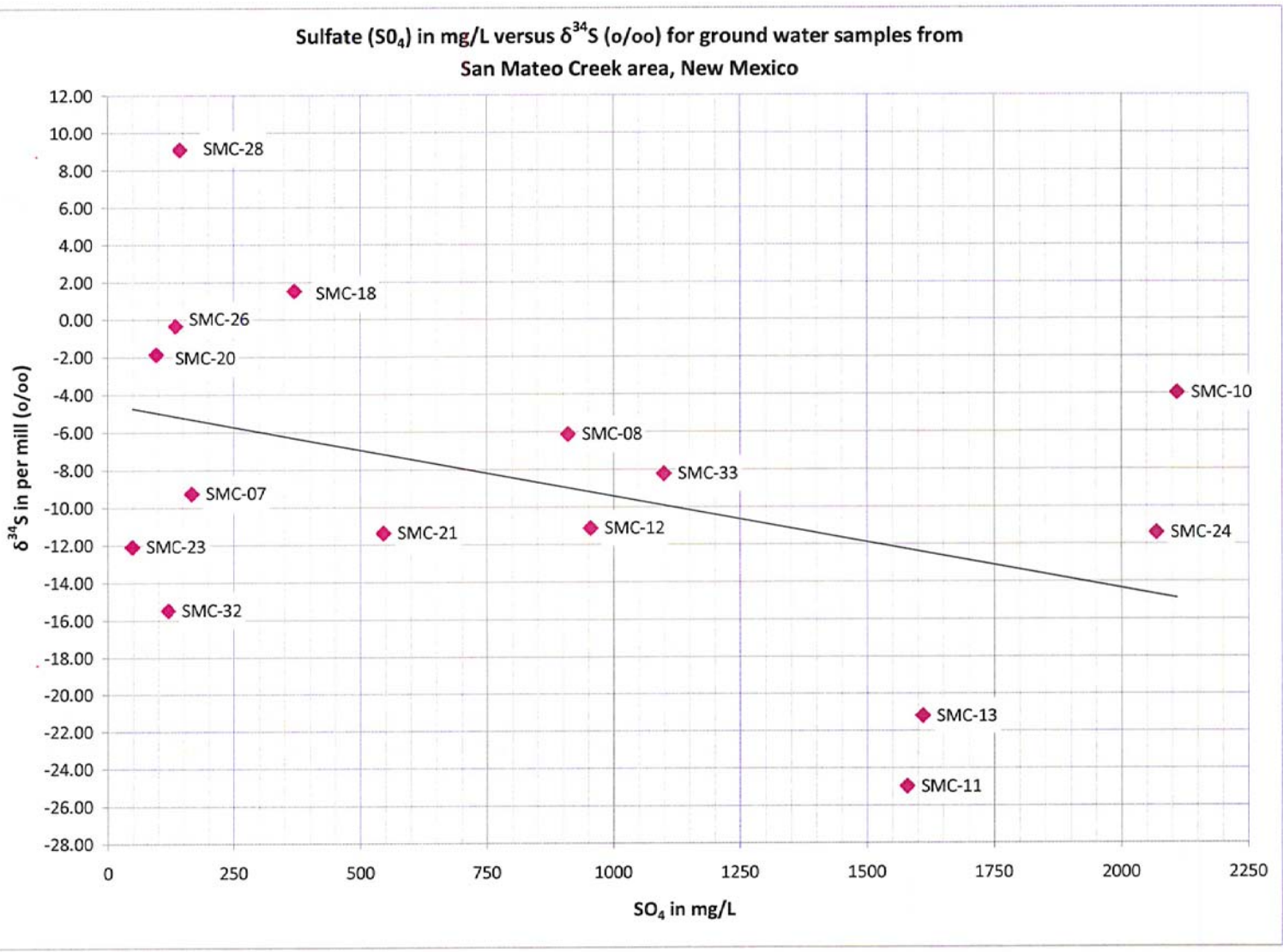
Figure 41. Chart comparing average major ion concentration values for the Bluewater and San Mateo area sample groups, Grants Mineral Belt, New Mexico.
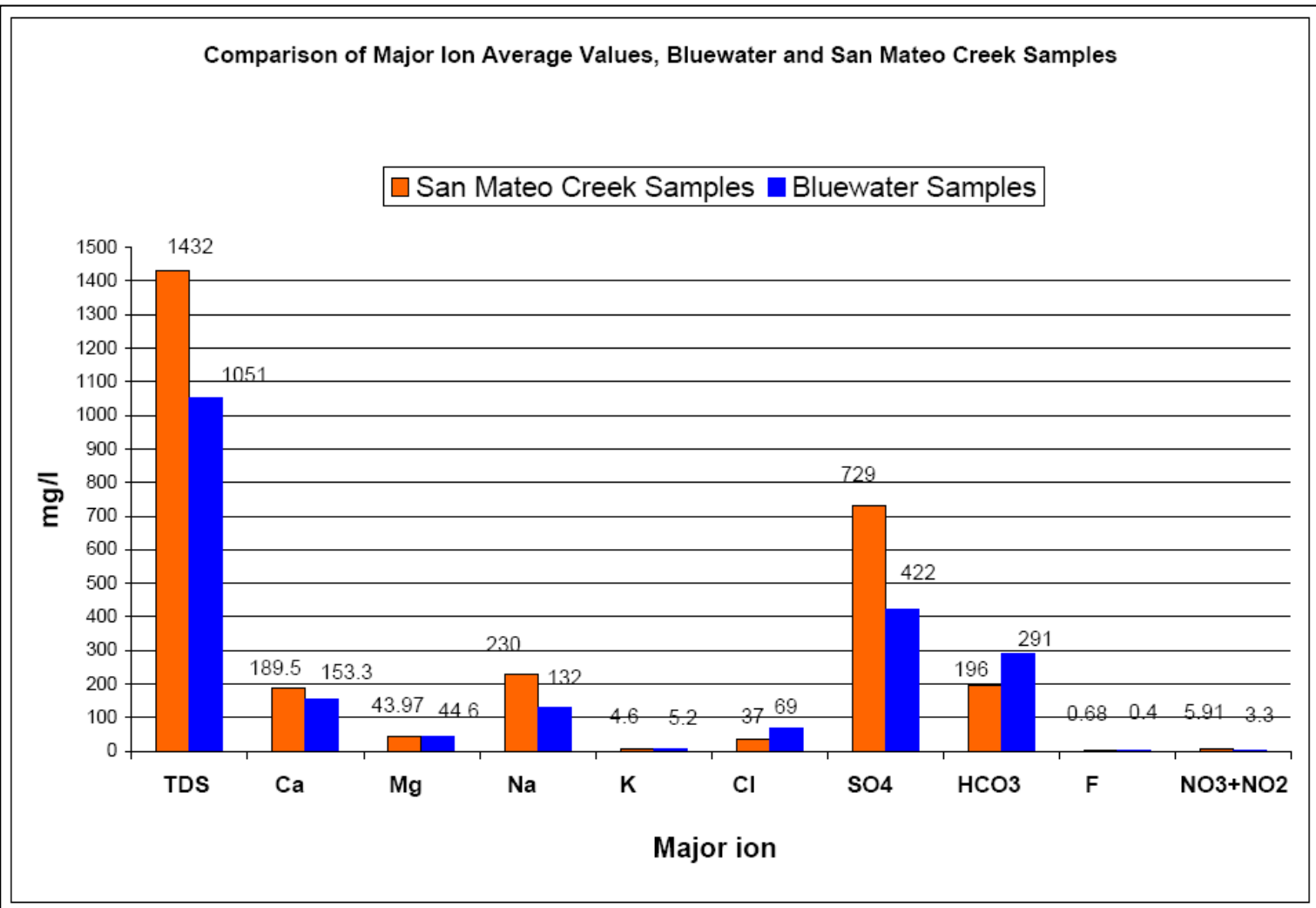
Figure 42. Chart comparing the average select trace element concentration values for the Bluewater and San Mateo area sample groups, Grants Mineral Belt, New Mexico.
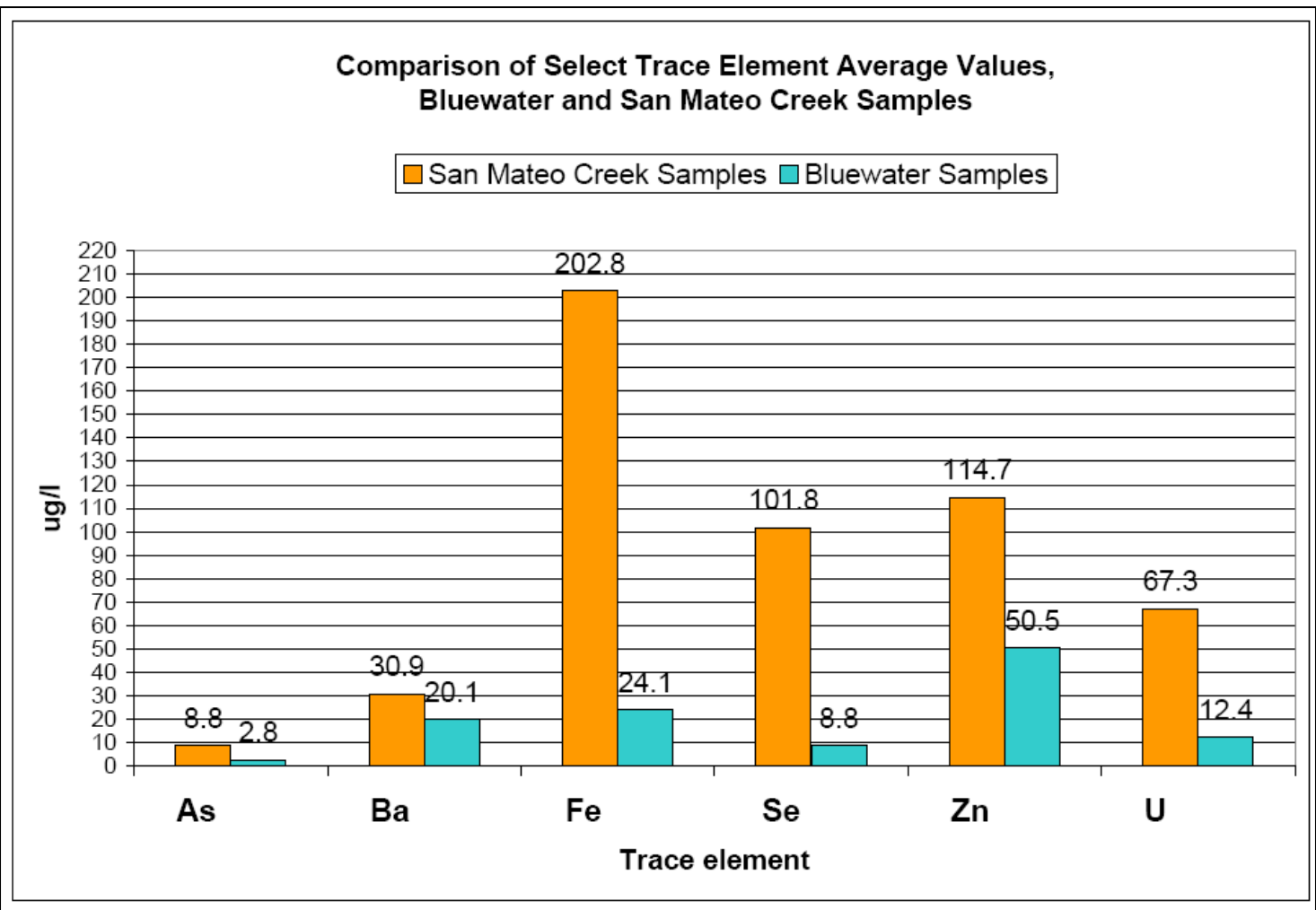
Figure 43. Trilinear (Piper) diagram with Bluewater and San Mateo Creek samples depicted
against average values described in the investigation by Brod, 1979.
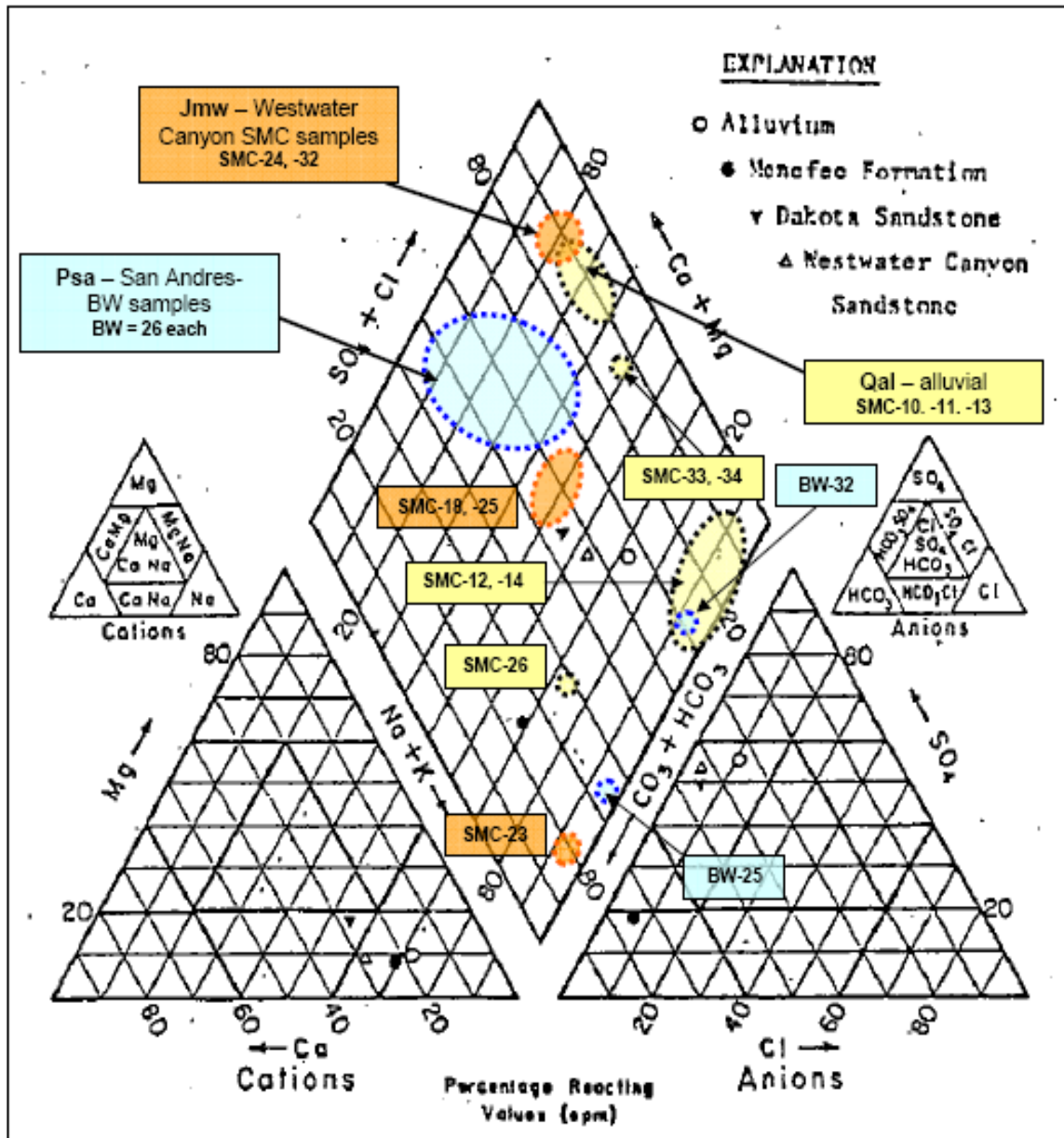
Table 1. List of field parameters and laboratory analytes measured in ground water samples for the Site Investigation of the San Mateo Creek Basin, New Mexico.

A. Field parameters: Electrical conductivity (EC); pH; temperature; dissolved oxygen (DO); oxidation-reduction potential (ORP or Eh).

B. Laboratory analytes through CLP:

Analyte	Minimum required analytical detection limit (µg/L)	Analyte	Minimum required analytical detection limit (µg/L)
pH laboratory	NS	Chromium (Cr)	50[1]
Calcium (Ca)	5000	Cobalt (Co)	50[1]
Magnesium (Mg)	5000	Copper (Cu)	1,000[1]
Sodium (Na)	5000	Iron (Fe)	300[2]
Potassium (K)	5000	Mercury (Hg)	2[1,5]
Carbonate (CO$_3$)	NS	Manganese (Mn)	50[2]
Bicarbonate (HCO$_3$)	NS	Nickel (Ni)	200[1]
Sulfate (SO$_4$)	250,000[2]	Lead (Pb)	156
Chloride (Cl)	250,000[1,2]	Magnesium	5,000
Nitrate + nitrite (NO$_3$+NO$_2$)	10,000[3]	Molybdenum (Mo)	1,000[1]
Fluoride (F)	1,600[1]	Silver (Ag)	50[1]
Aluminum (Al)	200[4]	Selenium (Se)	50[1,5]
Antimony (Sb)	6[5]	Thallium (Tl)	2[5]
Arsenic (As)	10[5]	Uranium (U)	30[1,5]
Barium (Ba)	1000[1]	Vanadium (V)	50
Beryllium (Be)	4[5]	Zinc (Zn)	5,000[1]
Cadmium (Cd)	5[5]		

C. Laboratory analytes through SLD:

Analyte	Minimum required analytical
Gross Alpha	15 pCi/L[5]
Radium-226 + 228 (^{226}Ra + ^{228}Ra)	5[5]
Gross Beta	NS

D. Laboratory analytes through either CLP or SLD:

Analyte	Minimum required analytical
Total Dissolved Solids	500,000

[1]New Mexico Water Quality Commission ("NMWQCC") ground water quality standard. [2]Federal secondary maximum contaminant level ("SMCL"). [3]NMWQCC ground water quality standard and Federal primary maximum contaminant level ("MCL") for nitrate. [4]Maximum SMCL for aluminum. [5]Federal MCL. [6]Federal lead treatment technology action level.

Table 2. Anaconda Bluewater Mill uranium mill tailings chemical water quality, Bluewater area, New Mexico (Perkins and Goad, 1980).

Sample date	10/26/77	11/17/78	11/07/79
TSS (mg/L)	20.5		52
TDS (mg/L)	17, 850		37,275
Conductivity (umohs)	19,635	54,285	65,714
pH	2.15		0.87
As (mg/L)	0.62	3.0645	3.07
Ba (mg/L)	0.55	0.187	0.241
Se (mg/L)	0.006	0.0702	6.966
Mo (mg/L)	0.16	0.6936	0.955
NH$_3$ (mg/L)	56.9	105.25	106.0
Na (mg/L)	2,118.3	1,738	1111.0
Cl (mg/L)	3,111.9	2,354.3	1,252.2
SO$_4$ (mg/L)	8,521.6	22,792	33,812
Ca (mg/L)		688.0	320.0
K (mg/L)		100.62	126.4
Cd (mg/L)		0.0972	0.096
NO$_3$+NO$_2$ (mg/L)		14.11	<0.01
Mg (mg/L)		0.554	1,440
V (mg/L)		43.9	48.96
Zn (mg/L)		12.390	<0.250
Al (mg/L)			1120
Pb (mg/L)		0.0554	1.440
Gross Alpha (pCi/L)		45,000 +/- 2,000	2,200 +/- 100
Ra-226 (pCi/L)	1,800 +/- 100	50 +_/- 2	15 +/- 4
Ra-228 (pCi/L)	0 +/- 2		
Pb-210 (pCi/L)	1,200 +/- 100		
U (mg/L)	53.0	47.62	18.5

Table 3. National Uranium Resource Evaluation (NURE) ground water sample uranium concentration values from the Bluewater, Milan, and Dos Lomas 7.5 minute quadrangles.

Bluewater 7.5' Quadrangle sample number	Sample location surface gamma reading converted to ppm uranium	Uranium concentration value in water sample (ppb - ug/L)
1081331	n/a	5.24
1081398	n/a	0.98
1081709	2	0.43
1081710	4	0.57
Milan 7.5' Quadrangle sample number		
1081306	n/a	3.63
1081399	3	5.9
1081400	7	5.01
1081401	n/a	3.33
1081697	16	6.76
1081698	4	8.55
1081699	6	3.15
1081700	5	69.72
1081701	7	1.67
1081702	8	0.96
1081703	8	0.59
1081704	4	0.63
1081705	8	1.0
1081706	12	0.81
1081707	14	1.53
Dos Lomas 7.5' Quadrangle sample numbers		
1081334	20	27.90
1081337	9	32.83
1081342	n/a	38.26
1081738	3	26.15
1081739	5	49.48
1081742	2	17.91

Table 4. Summary of analytical data for uranium mining industrial discharges into the Arroyo del Puerto surface water system, San Mateo Creek area, Grants Mineral Belt, New Mexico (after EPA, 1975).

Tabla 3
SUMMARY OF ANALYTICAL DATA FOR INDUSTRIAL DISCHARGES
GRANTS MINERAL BELT SURVEY
February 26-March 6, 1975

Station Description	Average Flow (mgd)	Number Composite Samples	Gross Alpha (pCi/l)			Radium 226 (pCi/l)			Uranium (mg/l)			Total Suspended Solids (mg/l)			Selenium (mg/l)			Vanadium (mg/l)		
			Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Kerr-McGee I-X Tailings Bypass	0.64	3	600	430	510	157	148	151	4.2	1.3	2.5	31	16	25	0.07	0.03	0.05	1.0	0.7	0.9
Kerr-McGee Sec 30W Mine Dischg	1.36	3	1,400	1,300	1,400	174	154	163	6.7	5.9	6.2	26	17	22	0.04	0.03	0.03	0.8	0.7	0.7
Kerr-McGee Sec 19 Mine Discharge	0.15	1	--	--	72	-	-	9.3	-	-	0.23	-	-	16	-	-	<0.01	-	-	0.6
Kerr-McGee Sec 35 Mine Discharge	3.77	3	3,000	2,400	2.700	68	32	51	26	14	19	120	86	100	0.08	0.04	0.07	1.0	0.6	0.8
Kerr-McGee Sec 36 Mine West Discharge	2.07	3	850	570	680	178	101	131	3.4	2.6	3.0	44	33	38	0.01	<0.01	<0.01	1.0	0.8	0.9
Kerr-McGee Sec 36 Mine East Discharge	0.14	3	580	510	560	72	59	65	2.5	2.3	2.4	32	27	29	0.03	<0.01	0.01	0.8	0.4	0.6
Kerr-McGee Seepage below Tailings Pond	-	1	-	-	144,000	-	-	65	-	-	160	-	-	38	-	-	0.70	-	-	5.6
Ranchers Exploration-Johnny M Mine Discharge	0.46	1	-	-	20	-	-	1.6	-	-	0.12	-	-	7	-	-	<0.01	-	-	<0.3
United Nuclear Corp. Ion-Exchange Discharge	0.08	3	2,300	1,400	1,800	39	14.3	31	11	5.9	7.8	7	3	5	0.12	0.02	0.08	0.5	<0.3	0.3

Table 5. Summary of analytical data from stream station surface water samples along the Arroyo del Puerto and San Mateo Creek drainages, Grants Mineral Belt, New Mexico (after EPA, 1975).

Table 3

SUMMARY OF ANALYTICAL DATA

FOR

SURFACE WATER SAMPLING

Station Description	Number of Samples	Gross Alpha (pCi/l)			Radium-226 (pCi/l)			Uranium (mg/l)			Selenium (mg/l)			Vanadium (mg/l)		
		Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Arroyo del Puerto downstream of Kerr-McGee Mill	3	1,700	1,400	1,500	50	45	47	12	5.0	7.7	0.16	0.13	0.15	1.0	0.6	0.8
Arroyo del Puerto near the mouth	3	1,500	750	1,100	7.2	6.1	6.5	6.6	4.7	5.8	0.07	0.01	0.04	1.9	0.5	1.1
San Mateo Creek at Highway 53 Bridge	1	-	-	1,000	-	-	1.09	-	-	4.7	-	-	0.02	-	-	<0.3

Table 6. Well construction information for the Bluewater set of wells sampled in this investigation (p. 1 of 3).

Bluewater Site Investigation wells

Sample ID	LATITUDE (NAD83)	LONGITUDE (NAD83)	OSE well permit no.	Well Depth (ft)	screened depth (ft)	lithology opposite perforations	Depth to water at completion (ft)/ Comments	Ref. i record no.	HMC well no.	Well depth (ft)	Completion interval depth (ft)	SA top elevation (Ref.	Latest water level elevation	Date	Ref. Error! Bookmark not defined. page	Comments
BWSI-00																Field blank
BWSI-02	35.225595	-107.888629		498					965							
BWSI-03	35.227344	-107.888396							986	467	420-467	6134	6426	08/23/2008	8.0-6	
BWSI-04	35.229749	-107.888762							991	500			6424.18	08/26/2008	8.0-6	
BWSI-05	35.258875	-107.972292	B-461	518			147	20								
BWSI-06	35.231733	-107.923966							938			6449	6432.3	12/17/2008	8.0-6	
BWSI-07	35.265414	-107.994713	B-1521	255	220-225	limestone	100	7								
BWSI-08	35.265967	-107.975864	B-1541	265	200-220	white sandstone	82	5								
BWSI-09	35.248517	-107.976643	B-1662	345			175	6								
BWSI-10	35.256567	-107.966417														
BWSI-11	35.255950	-107.967767														
BWSI-12	35.242589	-107.963738	B-1637	260		white sandstone	240	9								
BWSI-13	35.239510	-107.961517	B-1663	280	240-280	brown sandstone	180	8								
BWSI-14	35.252936	-107.981026	B-1688	380	340-380	red sandstone	140	11								
BWSI-15	35.218020	-107.912511	B-49	188			94	14	911	188					8.0-6	
BWSI-16	35.213846	-107.912278	B-50	175				15	998	145					8.0-7	
BWSI-17	35.233128	-107.944206														
BWSI-18	35.242809	-107.924478							936	160	100-160				4.1-21	Listed by HMC as alluvial well
BWSI-19	35.236342	-107.932447	B-518	250	210-250	sandstone, gravel, conglomerate	140	1								
BWSI-20	35.233410	-107.912254	B-50A	330		limestone and	75	16	545							

Sample [Table 4 E (NAD83)	LONGITUDE (NAD83)	OSE well permit no.	Well Depth (ft)	screened depth (ft)	lithology opposite perforations	Depth to water at completion (ft)/ Comments	Ref. i record no.	HMC well no.	Well depth (ft)	Completion interval depth (ft)	SA top elevation (Ref.	Latest water level elevation	Date	Ref. Error! Bookmark not defined. page	Comments
					sandstone										
BWSI-21	35.203787	-107.908264	B-18	275			152	17								
BWSI-22	35.203835	-107.915436	B-19	275			152	18								
BWSI-23	35.234271	-107.888866	B-44	542			96	13	949	551	505-551	6102	6431.7	02/13/2008	8.0-6	
BWSI-24	35.261930	-107.974420	B-637	587			137	19								
BWSI-25	35.271106	-107.957824														Site monitor well L(SG)
BWSI-26	35.268777	-107.938559	B-876/B-410-0-14	400	159-280			4								Site monitor well S(SG)
BWSI-27	35.271529	-107.938604	B-410-0-22	355	152-350	limestone and sandstone	147.6	3								Site monitor well OBS-3
BWSI-28	35.266163	-107.907318	B-410-0-10	330	234-333?	fine grained sandstone, dolomite, limestone, claystone	Lost circulation precluded completion through entire San Andres	2								Site monitor well I(SG)
BWSI-29	35.242032	-107.855229	B-28	1000			137	23	#!1 Deepwell	1000	919-999	5629	6484.68	12/12/2007	8.0-6	
BWSI-30	35.239529	-107.864253	B-28-S	980			135	24	#2 Deepwell	870		5776	6366.86	05/04/2005	8.0-6	
BWSI-32	35.255295	-107.861760							928	864		5795	6428.3	12/22/2008	8.0-6	
BWSI-33	35.225191	-107.876176	B-28-S-329	978	703-978		113	21	943	978	703-978	5852	6422.61	12/29/2008	8.0-6	
BWSI-34	35.247480	-107.923981	B-28-S-247	275			152	22	951	275	241-275	6346	6423.42	12/29/2008	8.0-6	
BWSI-35	35.279927	-107.831931	B-1458	702	682-702	red shale & clay, limestone	156	10								

Table 6. Well construction information for the Bluewater set of wells sampled in this investigation (p. 3 of 3).

Sample ID [Table 4	LATITUDE (NAD83)	LONGITUDE (NAD83)	OSE well permit no.	Well Depth (ft)	screened depth (ft)	lithology opposite perforations	Depth to water at completion (ft)/ Comments	Ref. i record no.	HMC well no.	Well depth (ft)	Completion interval depth (ft)	SA top elevation (Ref.	Latest water level elevation	Date	Ref. Error! Bookmark not defined. page	Comments
BWSI-38																Field blank
BWSI-39																Field duplicate associated with BWSI-09
BWSI-40																Field duplicate associated with BWSI-16
BWSI-41	35.23204621	-107.9146644							994	144	95-110		6458.8	11/14/2008	4.1-21	Listed by HMC as alluvial well
BWSI-42																Field duplicate associated with BWSI-41
BWSI-T																Field blank

i.   New Mexico Office of the State Engineer. Downloaded well records.

Sample ID	Alternative well IDs	Reference/page	Water Level (ft-BGS)	Reference/page	Well Depth (ft)	Reference/page	Screened interval	Reference/page	Lithology/stratigraphic unit opposite screened interval	Reference/page	Notes
SMC-00											
	Field Blank collected at SMC-01 well location										
SMC-01	BWSI-34	Error! Bookmark not defined.[1]/19	150	Error! Bookmark not defined./8.0-6	275	Error! Bookmark not defined./8.0-6	241-275	Error! Bookmark not defined./8.0-6	limestone/dolomite/chalk		20-Mar
						20-Mar					
	HMC-951										
	B28-S-247	[2]	152	[3]/20							
SMC-03	B00686*		81	21-Mar	138	21-Mar	120-134	21-Mar	sandstone/gravel/		21-Mar
									conglomerate		
SMC-04					340	[4]/1					
SMC-05	B-01072*		180	22-Mar	280	2-Apr	484-510	22-Mar	sandstone/gravel/		22-Mar
					510	22-Mar			conglomerate		
SMC-06	Field Blank collected at SMC-07 well location										
SMC-07					1200	[5]/2					
	14.9.18.243	[6]/99	744	Jun-99	800	Jun-99				Westwater Canyon	Jun-99
SMC-08			~28	[7]/1	~200	2-Jul					
SMC-09											
SMC-10	HMC-914		42	Error! Bookmark not defined./4.1-20	93	Error! Bookmark not defined./4.1-20				alluvium	Error! Bookmark not defined./4.1-20

Sample ID	Alternative well IDs	Reference/ page	Water Level (ft-BGS)	Reference/ page	Well Depth (ft)		Reference/ page	Screened interval		Reference/ page		Lithology/ stratigraphic unit opposite screened interval		Reference/ page	Notes
	12.9.7.343**	Jun-96	8 (11/30/195	Jun-96	98		Jun-96					sand and gravel (alluvium)		Jun-96	
		[8]/91		Aug-91			Aug-91							Aug-91	
SMC-11	HMC-920		33	Error! Bookmark not defined./4.1-20								alluvium		Error! Bookmark not defined./4.1-20	
	12.10.12.433	Jun-96	.6 (11/30/19	Jun-96	100		Jun-96					alluvium		Jun-96	
		Aug-92		Aug-92			Aug-92							Aug-92	
SMC-12	HMC-950		26	Error! Bookmark not defined./4.1-21	81		Error! Bookmark not defined./4.1-21					alluvium		Error! Bookmark not defined./4.1-21	
	12.10.12.221	Jun-96	.7 (07/26/19	Jun-96	91		Jun-96					alluvium		Jun-96	
		Aug-91		Aug-91			Aug-91							Aug-91	
SMC-13	HMC-921		39	Error! Bookmark not defined./4.1-21	73		Error! Bookmark not defined./4.1-21					alluvium		Error! Bookmark not defined./4.1-21	
	B00415 O-13*		50	23-Mar	74		23-Mar								
SMC-14	21.10.14.212	Jun-96	0.1 (07/1956	Jun-96								alluvium		Jun-96	
	HMC-922		51	Error! Bookmark not defined./4.1-21		96	Error! Bookmark not defined./4.1-21					alluvium		Error! Bookmark not defined./4.1-20	
			59	Error! Bookmark not defined./34		101	[9]Error! Bookmark not defined./34								
SMC-15	nt blank post SMC-13														
SMC-16															pump set at ~200' (Ref. 9, p. 46)
SMC-17			65.5	Sep-46	>400		Sep-46								

Table 7. Well construction information for the San Mateo Creek set of wells sampled in this investigation (p. 3 of 5).

Sample ID	Alternative well IDs	Reference/page	Water Level (ft-BGS)	Reference/page	Well Depth (ft)		Reference/page	Screened interval		Reference/page		Lithology/stratigraphic unit opposite screened interval		Reference/page	Notes
SMC-18			82.3	15-Nov	102		15-Nov								
SMC-20	B-01115	[10]/11	204	25-Mar	478		11/16. 3/25	458-478		25-Mar			sandstone/gravel/conglomerate	25-Mar	
	Strathmore-11	10Error! Bookmark not defined./5			478		5-Oct								
SMC-21															
SMC-22	B-01485*		280	4-Mar		580	4-Mar	500-560		4-Mar			red coarse sandstone, red sandstone	5-Mar	Former supply to mine camp (Ref. 9, p. 44)
						~500	3-Jul								
SMC-23	trathmore-11	5-Oct	80	1-Mar		260	1-Mar	220-260		2-Mar			Jmw	5-Sep	
	B-1636	Sep-31											white sand	3-Mar	
	B-0659*		190	6-Mar		220	6-Mar						sandstone/Dakota	3/6/2007	
SMC-24	trathmore-13	10Error! Bookmark not defined./5	86	12-Oct		170	12-Oct						Jmw	Error! Bookmark not defined./9	
	B-0659*		190	6-Mar		220	6-Mar						sandstone/Dakota	3/6/2007	
SMC-25	B-1636*		80	1-Mar		260	1-Mar	220-260		2-Mar			white sand	3-Mar	
	13.9.22.111*	Jun-99	220	Jun-99									Westwater Canyon	Jun-99	
SMC-26	Strathmore-115	10Error! Bookmark not defined./5	88	1012		88	5-Oct						Qal	10/9, 12	
						130	12-Oct								
	B-00415-O5*		72	26-Mar		95	26-Mar								

Sample ID	Alternative well IDs	Reference/page	Water Level (ft-BGS)	Reference/page	Well Depth (ft)	Reference/page	Screened interval	Reference/page	Lithology/stratigraphic unit opposite screened interval	Reference/page	Notes
	B-00415-O6*		73	27-Mar	90	27-Mar			Shallow alluvium/basin fill	3/26, 28	
	B-00415-O7*		74	28-Mar	80	28-Mar					
SMC-28			520	4-May	590	4-May					
SMC-30	B-00815*		260	29-Mar	300	29-Mar	270-290	29-Mar	white sandstone	29-Mar	
SMC-31	B-00524*		260	30-Mar	520	30-Mar	400-480	30-Mar	gray coarse sand	30-Mar	
	13.8.24.341*	Jun-97			250	Jun-97					
	13.8.24.341*	Jun-97	139 (5/1978)	Jun-97	500	Jun-97					
SMC-32	13.9.16.411*	Jun-98			250	Jun-98			Westwater Canyon	Jun-98	Pump set at ~200' (Ref. 9, p. 44)
	13.9.16.413*	Jun-99			250	Jun-99			Westwater Canyon	Jun-99	
SMC-33	B-00415-O8*		30	3/31, 33, 34	54	31-Mar			shallow alluvium/basin fill	3/31, 32	
	B-00415-O9*				57	Mar-32					
	B-00415-O10*		32	Mar-32	59	Mar-33					
	B-00415-O11*				72	Mar-34					
	13.9.29.341*	Jun-99	dry	Jun-99	190	Jun-99			San Rafael Group	Jun-99	abandoned
	19.9.29.341*	Jun-99			455	Jun-99					
SMC-34	13.9.28.111**		58.2 (08/05/19?	Jun-99	125	Jun-99			alluvium	Jun-99	
SMC-35	te associated with SMC-11										
SMC-36	te associated with SMC-26										
SMC-39			86.6	[11]/XX	88	11/XX					Low yield; Isotope sample only.
	13.9.22.212*	Jun-99	7.5 (12/1957	Jun-99	95	Jun-99			alluvium	Jun-99	
	13.9.22.212*	Jun-99	7.1 (03/1975	Jun-99	130	Jun-99			alluvium	Jun-99	
**	dentification from Ref. [12]										

Sample ID	Alternative well IDs	Reference/page	Water Level (ft-BGS)	Reference/page	Well Depth (ft)		Reference/page	Screened interval		Reference/page		Lithology/ stratigraphic unit opposite screened interval		Reference/page	Notes
[1].	onda Company Bluewater uranium millsite, CERCLIS ID NMD007106891, Cibola County, New Mexico."														
[2].	for well permit numbers." Email sent to David L. Mayerson.														
[3].	essed through iWATERS (http://nmwrrs.ose.state.nm.us/WRDispatcher).														
[4].	Homestake Mining Company (HMC) project book.														
[5].	dated. "Residential well water sampling sign-up sheet."														
[6].	rea, McKinley and Valencia counties, New Mexico." New Mexico Institute of Mining and Technology Masters thesis.														
[7].	partment. Residential well questionnaires.														
[8].	water area, Valencia County, New Mexico." New Mexico State Engineer Technical Report 20.														
[9].	t. Field notebook for Grants Uranium belt projects.														
[10].	ry 10, 2009. "Compiled San Mateo well data." Emailed data transmittal to NMED.														
[11].	artment, 2009. Well sampling field sheets.														
[12].	howing geospatial position of historical wells compiled from various sources relative to wells sampled by NMED).														

Table 8. Summary of data values describing: the sample number; field parameters; individual and average chemical values; and isotopic results for the 2008 Bluewater set of ground water samples (p. 1 of 3).

Sample Number	Latitude (NAD83)	Longitude (NAD83)	Sample Date	Tempera-ture (T) °C	Dissolved Oxygen (DO) mg/L	Specific Conduc-tance (SC) µS/cm	Oxidation Reduction Potential (ORP)	Field pH	Lab pH	Total Dissolved Solids (TDS) mg/L	Total anions meq/L	Total cations meq/L	Charge balance error	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)
EPA MCL																	
NM WQCC								6 - 9		1000			<10%				
BW-02	35.225595	-107.888629	8/25/2008	16.23	2.00	1289	69.40	6.89	7.20	1010	15.33	16.58	3.91	159	47.1	106	6.19
BW-03	35.227344	-107.888396	8/25/2008	16.5	2.21	1379	99.80	6.79	7.20	1110	16.26	18.24	5.71	171	49.4	126	6.11
BW-04	35.229749	-107.888762	8/27/2008	16.2	3.68	1273	-22.00	6.90	7.30	940	15.31	16.84	4.76	160	50.2	105	6.16
BW-05	35.258875	-107.972292	8/25/2008	18.51	1.98	1613	118.60	6.69	7.00	1280	18.62	20.72	5.34	170	52.7	178	6.32
BW-06	35.231733	-107.923966	8/25/2008	13.25	4.15	1115	118.50	7.14	7.30	664	9.61	10.72	5.49	109	38.5	46.9	2.9
BW-07	35.265414	-107.994713	8/26/2008	15.29	1.84	3231	147.40	6.34	6.80	3110	45.21	47.59	2.56	422	96.1	420	13.7
BW-08	35.265967	-107.975864	8/26/2008	14.9	4.86	847	115.60	6.98	7.30	714	9.95	11.49	7.21	138	35.2	37.3	3.38
BW-09	35.248517	-107.976643	8/26/2008	13.94	15.87	1068	135.20	6.66	7.20	916	13.2	14.98	6.2	164	43.3	71.1	5.46
BW-10	35.256567	-107.966417	8/26/2008	14.43	9.67	982	160.10	6.55	7.20	774	11.05	12.73	7.06	165	35.3	34.9	2.69
BW-11	35.255950	-107.967767	8/26/2008	14.58	8.62	910	170.10	6.55	7.20	740	10.18	11.33	5.34	147	33.6	26.5	2.97
BW-12	35.242589	-107.963738	8/27/2008	13.52	3.90	1474	153.00	6.84	7.20	832	13.41	15.37	6.8	143	47.0	95.7	7.83
BW-13	35.239510	-107.961517	8/27/2008	13.67	3.89	1446	191.60	6.82	7.20	844	12.99	14.92	6.9	149	44.8	83.7	6.1
BW-14	35.252936	-107.981026	8/27/2008	15.01	5.32	1688	132.30	6.58	7.10	964	15.51	17.21	5.21	196	59.4	56.1	3.99
BW-15	35.218020	-107.912511	8/25/2008	13.96	13.15	1033	113.90	7.25	7.40	848	11.93	12.76	3.35	134	39.1	63.5	3.59
BW-16	35.213846	-107.912278	8/27/2008	n/a	n/a	n/a	n/a	n/a	7.40	812	13.06	14.47	5.15	148	41.9	80.6	3.92
BW-17	35.233128	-107.944206	8/28/2008	15.55	7.89	788	104.20	7.14	7.50	510	7.43	8.59	7.23	79.3	37.7	33.8	2.18
BW-18	35.242809	-107.924478	8/28/2008	16.95	7.76	1804	80.50	6.99	7.40	1210	18.42	20.47	5.28	228	48.2	116	3.11
BW-19	35.236342	-107.932447	8/28/2008	13.62	4.98	1113	197.30	6.85	7.30	738	10.86	13.01	9	131	43.7	63.8	3.8
BW-20	35.233410	-107.912254	8/28/2008	13.88	5.12	1373	37.00	7.15	7.30	876	14.06	16.11	6.78	185	52.3	56.6	4.39
BW-21	35.203787	-107.908264	8/25/2008	14.21	10.81	995	129.70	7.25	7.30	732	11.4	12.48	4.53	125	36.5	72.5	3.45
BW-22	35.203835	-107.915436	8/25/2008	15.31	10.48	644	134.60	7.52	7.50	422	6.68	7.53	5.99	73.3	29.2	32.5	2.22
BW-23	35.234271	-107.888866	8/25/2008	16.35	8.24	1624	135.60	7.06	7.20	1230	18.3	19.78	3.88	187	54.5	133	7.02
BW-24	35.261930	-107.974420	8/25/2008	15.42	1.53	2101	125.50	6.72	7.00	1300	18.92	21.18	5.63	167	53.5	191	5.34
BW-25	35.271106	-107.957824	8/27/2008	17.16	0.81	1344	-232.8	10.21	10.00	704	7.87	14.76	30.48	0.6	1.9	332	5.47
BW-26	35.268777	-107.938559	8/27/2008	17.94	1.03	6753	-75.4	5.40	5.00	4720	74.63	47.86	21.86	758	61.6	113	1.84
BW-27	35.271529	-107.938604	8/27/2008	17.7	2.76	3727	-119.6	6.48	6.10	2460	39.96	38.69	1.61	83.5	132.0	535	15.3
BW-28	35.266163	-107.907318	8/27/2008	15.38	0.89	1175	88.60	8.66	9.20	584	9.56	10.1	2.72	14.5	10.8	192	5.22
BW-29	35.242032	-107.855229	8/27/2008	20.47	3.97	2828	124.40	6.69	6.80	1840	29.75	31.53	2.91	225	77.8	312	13
BW-30	35.239529	-107.864253	8/27/2008	18.13	9.00	2530	132.20	6.75	6.90	2200	28.06	30.54	4.23	231	78.1	282	12.6
BW-32	35.255295	-107.861760	9/16/2008	14.95	0.81	1858	74.00	8.27	8.48	1150	17.75	19.56	4.84	15.2	4.3	423	1.56
BW-33	35.225191	-107.876176	9/16/2008	18.66	0.93	2079	121.60	6.86	7.72	1660	24.67	27.13	4.75	187	62.2	286	9.36
BW-34	35.247480	-107.923981	8/27/2008	13.92	8.95	1254	172.80	7.22	7.20	972	14.17	16.38	7.23	159	47.5	101	5.62
BW-35	35.279927	-107.831931	8/25/2008	22.99	3.80	3857	64.90	8.48	7.20	1010	15.33	16.58	3.91	159	47.1	106	6.19
Average values	n/a	n/a	n/a	15.89	5.34	1787	n/a	7.08	7.31	1208	18.16	19.04	5.06	169	48.3	149	5.73

Table 8. Summary of data values describing: the sample number; field parameters; individual and average chemical values; and isotopic results for the 2008 Bluewater set of ground water samples (p. 2 of 3).

Sample Number	Cl (mg/L)	SO₄ (mg/L)	HCO₃ (mg/L)	Ag (µg/L)	Al (µg/L)	As (µg/L)	Ba (µg/L)	Be (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe (µg/L)	Hg (µg/L)	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	NO₃+NO₂ (mg/L)	Pb (µg/L)	Sb (µg/L)
EPA MCL						10	2000	4	5		100	1300	4		2				10	15	6
NM WQCC	250	600		50	5000{i}	100	1000		10	50{i}	50	1000	1.6	1000	2	200	1000{i}	200{i}	10	50	
BW-02	65	434	267	<10	<100	<2	12.3	<5	<5	<20	<20	<20	0.43	<25	<0.2	<5	<2	<20	3.83	<2	<2
BW-03	73	463	273	<10	<100	<2	13.3	<5	<5	<20	<20	<20	0.41	<25	<0.2	<5	<2	<20	4.28	<2	<2
BW-04	67	434	262	<10	<100	<2	21.3	<5	<5	<20	<20	<20	0.46	177	0.21	27.6	<2	<20	4.13	<2	<2
BW-05	101	475	356	<10	<100	2.2	11.7	<5	<5	<20	<20	<20	0.38	<25	<0.2	5.3	<2	<20	1.75	<2	<2
BW-06	20	249	230	<10	<100	<2	20.1	<5	<5	<20	<20	<20	0.31	<25	<0.2	<5	<2	<20	4.39	<2	<2
BW-07	262	1440	476	<10	<100	5.1	<10	<5	<5	<20	<20	<20	0.58	53.9	<0.2	<5	<2	<20	0.33	<2	<2
BW-08	25	245	249	<10	<100	5	<10	<5	<5	<20	<20	<20	0.29	<25	<0.2	<5	<2	<20	2.69	<2	<2
BW-09	40	345	293	<10	<100	11.5	21.1	<5	<5	<20	<20	<20	0.45	<25	<0.2	<5	2.1	<20	4.18	<2	<2
BW-10	17	241	335	<10	<100	<2	30.3	<5	<5	<20	<20	<20	<0.25	<25	0.235	<5	<2	<20	2.79	<2	<2
BW-11	14	222	312	<10	<100	2.7	40.6	<5	<5	<20	<20	<20	<0.25	<25	<0.2	<5	<2	<20	2.24	<2	<2
BW-12	45	352	288	<10	<100	4.6	11.6	<5	<5	<20	<20	<20	0.54	<25	0.244	<5	<2	<20	3.83	<2	<2
BW-13	39	342	286	<10	<100	5.9	15.4	<5	<5	<20	<20	<20	0.56	<25	0.329	<5	<2	<20	3.46	<2	<2
BW-14	48	451	284	<10	<100	8.7	12.5	<5	<5	<20	<20	<20	0.58	<25	<0.2	5.7	<2	<20	4.79	<2	<2
BW-15	33	341	233	<10	<100	<2	41.6	<5	<5	<20	<20	<20	0.3	<25	<0.2	<5	<2	<20	4.13	<2	<2
BW-16	42	385	230	<10	<100	2.9	39.9	<5	<5	<20	<20	<20	0.33	<25	<0.2	<5	<2	<20	4.2	<2	<2
BW-17	11	181	200	<10	<100	<2	17.8	<5	<5	<20	<20	<20	0.26	<25	0.221	<5	3.3	<20	3.51	<2	<2
BW-18	147	529	188	<10	<100	<2	27.4	<5	<5	<20	<20	<20	<0.25	<25	<0.2	<5	<2	<20	10	<2	<2
BW-19	27	290	242	<10	<100	<2	24.5	<5	<5	<20	<20	<20	0.33	<25	0.201	<5	3.3	<20	4.65	<2	<2
BW-20	60	415	222	<10	<100	<2	23.3	<5	<5	<20	<20	<20	0.28	<25	0.236	<5	<2	<20	4.77	<2	<2
BW-21	31	329	220	<10	<100	2.2	29.2	<5	<5	<20	<20	<10	0.34	<25	<0.2	<5	<2	<20	3.36	<2	<2
BW-22	10	162	182	<10	<100	<2	21.5	<5	<5	<20	<20	24.3	0.37	<25	<0.2	<5	3.4	<20	1.4	<2	<2
BW-23	101	517	280	<10	<100	<2	11.8	<5	<5	<20	<20	<20	0.45	<25	<0.2	<5	<2	<20	4.76	<2	<2
BW-24	107	478	362	<10	<100	2	10.5	<5	<5	<20	<20	<20	0.28	45.4	<0.2	<5	<2	<20	0.34	<2	<2
BW-25	217	2.5	102	<10	<100	<2	<10	<5	<5	<20	<20	<20	0.38	<25	0.221	<5	16.5	<20	0.02	<2	<2
BW-26	2380	357	<5	<10	<100	3.7	73.5	<5	<5	<20	<20	<20	0.25	564000	0.268	66100	<2	<20	0.07	<2	<2
BW-27	996	567	<5	<10	<100	<2	<10	<5	<5	<20	<20	<20	0.25	1020	0.332	784	<2	<20	0.13	<2	<2
BW-28	216	103	80	<10	<100	<2	10	<5	<5	<20	<20	<20	0.26	68.5	0.307	77.3	<2	<20	0.07	<2	<2
BW-29	219	749	485	<10	<100	<2	<10	<5	<5	<20	<20	<20	0.25	87.2	0.309	14.9	<2	54.3	1.02	3.6	<2
BW-30	209	727	426	<10	<100	<2	10.8	<5	<5	<20	<20	<20	0.25	<25	0.266	<5	3.5	<20	2.33	<2	<2
BW-32	36.5	555	315	<1	<10	4	<100	<1	<1	<1	2	<10	n/a	<50	<0.2	6	9	<10	0.11	<1	<1
BW-33	139	678	400	<1	<10	2	<100	<1	<1	<1	2	<10	n/a	<50	<0.2	1	1	<10	4.8	<1	<1
BW-34	57	383	274	<10	<100	2.5	18.2	<5	<5	<20	<20	<20	0.47	33.4	<0.2	<5	<2	<20	4.61	<2	<2
BW-35	65	434	267	<10	<100	1	12.3	<5	<5	<20	<20	<20	0.43	<25	<0.2	<5	<2	<20	3.83	<2	<2
Average values	179	420	278	<10	<100	<5	22.4	<5	<5	<20	<20	<20	0.37	<20	0.26	<5	<2	<20	3.05	<2	<2

Table 8. Summary of data values describing: the sample number; field parameters; individual and average chemical values; and isotopic results for the 2008 Bluewater set of ground water samples (p. 3 of 3).

Sample Number	Se (µg/L)	Tl (µg/L)	V (µg/L)	Zn (µg/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	^{226}Ra (pCi/L)	^{228}Ra (pCi/L)	U (µg/L)	^{238}U (pCi/L)	^{235}U (pCi/L)	^{234}U (pCi/L)	$\partial\ ^2$H per mil (‰)	$\partial\ ^{18}$O per mil (‰)	$\partial\ ^{13}$C per mil (‰)	$\partial\ ^{34}$S per mil (‰)
EPA MCL	50	2			15	50	5	5	30							
NM WQCC	50			10000			30	30	30							
BW-02	10.9	<2	<20	32.8	1.9	12	-0.03	0.31	6.4	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-03	10.8	<2	<20	<20	7.3	9.1	0.24	0.2	11.7	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-04	9.2	<2	<20	<20	4.9	7.2	0.91	ND	7	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-05	4	<2	<20	261	10.4	14	-0.05	0.41	10.5	3	0.07	6.4	-75.0	-9.71	-6.32	10.09
BW-06	3.7	<2	<20	10	4	2.3	0.19	0.27	5.1	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-07	2.2	<2	<20	392	6.3	14.4	0.08	0.25	9.4	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-08	2.5	<2	<20	<20	1.8	5.6	ND	ND	4.9	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-09	4.8	<2	<20	<20	4.2	5.7	ND	ND	7.8	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-10	2	<2	<20	<20	5.1	2.5	0.05	0.39	5.5	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-11	<2	<2	<20	47.9	2.5	4.2	0.01	ND	5	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-12	4.7	<2	<20	10	4.1	6.5	0.23	0.15	6.8	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-13	3.8	<2	<20	53.8	5.2	5.7	0.09	0.24	6.4	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-14	10	<2	<20	38	7.4	5.8	0.38	0.29	10.5	3.4	0.08	13.8	-93.3	-12.40	-6.68	10.64
BW-15	10.1	<2	<20	<20	6.7	5.3	0.16	ND	12	2.8	0.1	4.5	-76.5	-10.05	-8.57	7.53
BW-16	18.8	<2	<20	<20	5.1	5.9	0.14	ND	17.7	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-17	3.9	<2	<20	43.7	3.6	2.2	0.05	ND	4.4	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-18	31	<2	<20	30.7	1.5	4	0.05	0.25	3.6	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-19	11.1	<2	<20	<20	5.3	10.3	0.08	ND	14.2	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-20	18.7	<2	<20	29.9	6.5	5	0.11	0.15	7.2	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-21	16.3	<2	<20	<20	7.2	4.9	0.19	0.01	11.8	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-22	7.3	<2	<20	20	4	2	0.15	ND	5.4	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-23	8.5	<2	<20	<20	12.6	13	0.2	0.22	13.8	4.3	0.4	7.1	-78.5	-10.15	-7.07	6.74
BW-24	4.1	<2	<20	201	11.3	16.1	0.32	0.41	10.9	3.2	0.1	14.4	-78.4	-10.20	-5.43	9.46
BW-25	<2	<2	<20	21.3	-0.7	5	ND	0.29	<2	-0.03	0.0008	0.01	-84.9	-10.68	n/a	n/a
BW-26	<2	<2	<20	26.9	-1.1	1	1.65	ND	<2	0.2	-0.1	0.4	-72.0	-9.01	n/a	8.55
BW-27	<2	<2	<20	<20	8.8	18.7	0.09	ND	<2	7.61	0.08	0.06	-73.6	-8.99	n/a	14.26
BW-28	<2	<2	<20	<20	0.9	3.4	0.01	ND	<2	0.04	-0.01	0.4	-73.3	-9.35	n/a	n/a
BW-29	7.3	<2	<20	126	7.5	15.8	0.25	0.22	8.9	0.3	r/a	n/a	n/a	n/a	n/a	n/a
BW-30	7.7	<2	<20	47.5	13.6	12.3	0.04	0.28	16.7	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-32	5	<1	<20	<10	29	10.8	0.11	ND	29	11	0.5	22.9	-77.0	-10.24	-8.49	-13.61
BW-33	16	<1	<20	<10	12.1	13.8	0.2	ND	20	n/a	r/a	n/a	n/a	n/a	n/a	n/a
BW-34	5.3	<2	<20	73.8	22.8	15.6	0.05	ND	53.3	12.3	0.5	13.5	-71.8	-9.63	-7.70	7.62
BW-35	10.9	<2	<20	32.8	3	0.4	0.19	0.16	6.4	n/a	r/a	n/a	n/a	n/a	n/a	n/a
Average values	9	<2	<20	78.9	6.8	7.9	0.2	0.25	11.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 9. Environmental issues, data gaps, and suggested solutions for the Bluewater area, New Mexico (p. 1 of 2).

Environmental Issue	Data Gap	Suggested Solution
1.Validity of placement of shallow wells to detect excursion or movement of contamination from mill site may be inadequate.	Direction of flow in the shallow aquifer with respect to faults is poor & out dated.	Update ground water flow direction in the shallow aquifer w/ potentiometric contour map based on more current information: geologic mapping, new monitoring wells, & pump test data if possible.
2. L (SG) well pH value (10) is elevated & not representative of background pH (7). Suspect other chemical concentrations at this well location are not representative of natural ground water conditions.	Source of elevated pH is unknown but suspected to be from carbonate-alkaline leach circuit waste water during early operation of mill site	Conduct geochemical study of ground water quality at the L (SG) well location and/or site & install new background monitoring well and re-evaluate monitoring program against new data for compliance.
3. Boring logs of deep monitoring wells (MWs) constructed to monitor San Andres Aquifer at U mill site suggest the wells may not be properly constructed-located to adequately monitor the complex hydrogeologic system at the mill site. Wells contain large sections of open borehole that may produce water from multiple zones causing sample water to be a mix or diluted fraction. Large fault systems between well locations may impede or enhance ground water flow.	Deep MWs at mill site may not be properly constructed-located to adequately understand & monitor impacts to San Andres Aquifer.	Review all historical information & boring logs describing the reasons for siting-constructing deep MWs. Determine if existing wells provide adequate monitoring of the complex hydrogeologic & hydrochemical ground water system beneath mill site. If wells are found to be inadequate then propose new well siting-construction-pump testing to better characterize & understand ground water system for long term monitoring.
4. San Andres Aquifer beneath the U mill site is contaminated with mill raffinate waste water from evaporation pond seepage & deep disposal well injection into Yeso-Abo Formation.	Source of contamination is unclear if it is from downward evaporation pond seepage, or upward from Yeso-Abo Formation injection seepage, or combination of both.	Determine if source(s) of contamination in San Andres Aquifer by expanded geochemical water sampling of existing MWs & new wells. Conduct pump-flow testing of Yeso-Abo Formation and/or San Andres Aquifer to determine if there is leakage or hydraulic communication between units.
5. Ground water pumpage in offsite deep wells completed in the San Andres Aquifer near south boundary of U mill site may cause contaminated water to be drawn off site past site boundary.	Amount of annual-seasonal ground water pumpage in nearby offsite wells unknown. Application of potentially contaminated ground water unknown.	Update deep ground water flow direction map to understand if contaminated water beneath mill site is migrating toward or being drawn toward offsite wells. Identify application of offsite ground water from wells near mill site boundary.

Table 9. Environmental issues, data gaps, and suggested solutions for the Bluewater area, New Mexico (p. 2 of 2).

Environmental Issue	Data Gap	Suggested Solution
6. Uranium concentration in nearby off site wells close to site boundary are elevated 2-3 times background range of U.	Source of elevated uranium concentration in offsite wells close to site boundary is unknown.	Conduct geochemical sampling of onsite & offsite wells using environmental isotopes of U & other geochemical parameters to determine locations where U is natural, anthropogenic, or mixture of two sources.
7. Bluewater Basin is critical, long-term potable water supply basin for agricultural, domestic, industrial, & municipal water supplies. It must be protected from degradation & threat of contamination from mill site.	The level of potential risk of degradation to the quality & quantity of the Bluewater Basin ground water supply from potentially contaminated water at the mill site is unknown.	Determine if Bluewater Basin water quality-quantity supply is at risk from contaminated mill site ground water & the effect of long term, offsite high volume pumping along fault systems that extend onto & beneath mill site.

Table 10. Summary of data values describing: the sample number; field parameters; individual and average chemical values; and isotopic results for the 2009 San Mateo Creek set of ground water samples (p. 1 of 3).

Sample Number	Latitude (NAD83)	Longitude (NAD83)	Sample Date	Tempera-ture (T) °C	Dissolved Oxygen (DO) mg/L	Specific Conduc-tance (SC) µS/cm	Oxidation Reduction Potential (ORP)	Field pH	Lab pH	Total Dissolved Solids (TDS) mg/L	Total anions meq/L	Total cations meq/L	Charge balance error	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)
EPA MCL																	
NM WQCC								6 - 9		1000			<10%				
SMC-03	35.204251	-107.897797	3/31/2009	13.28	4.55	1481	130.2	7.29	7.4	884	13.13	14.35	4.44	172	40.1	54.3	4.1
SMC-04	35.206449	-107.871402	3/31/2009	12.79	1.29	1291	25.2	8.57	8.4	698	9.83	9.94	0.56	11.2	3.24	208	2.4
SMC-05	35.204204	-107.872925	3/31/2009	15.09	3.24	1126	93.3	8.81	8.6	592	8.08	8.86	4.61	2.83	0.58	199	0.5
SMC-07	35.442460	-107.823329	4/1/2009	n/a	n/a	n/a	n/a	n/a	8.2	534	7.59	9.18	9.47	21.7	7.94	168	5.3
SMC-08	35.266714	-107.835451	3/30/2009	12.74	5.01	727	116.5	8.36	7.1	1400	21.34	22.11	1.77	106	23.4	341	2.3
SMC-09	35.238520	-107.784902	3/30/2009	12.77	70.70	898	92.8	7.47	7.4	3400	47.59	50.33	2.80	541	148	251	9.4
SMC-10	35.277739	-107.830824	3/30/2009	12.98	0.16	2341	-195.3	7.94	7.4	3380	48.41	52.09	3.65	567	149	261	7.0
SMC-11	35.276939	-107.844180	3/31/2009	13.05	0.20	3590	207.4	6.92	7.5	2440	37.55	43.14	6.94	479	88.5	269	10.1
SMC-12	35.289443	-107.839515	3/31/2009	12.43	4.10	3206	201.0	7.70	8	1870	27.08	31.12	6.94	59	10.3	628	0.5
SMC-13	35.275482	-107.850652	4/2/2009	13.52	1.52	2922	13.7	6.83	7.4	2710	38.46	41.13	3.36	389	73.7	355	8.4
SMC-14	35.275194	-107.859294	4/2/2009	11.8	0.17	1643	-222.5	8.76	8.7	1180	16.9	19.22	6.43	4.94	0.84	434	1.1
SMC-16	35.348006	-107.737150	4/1/2009	10.5	0.25	1184	-225.0	8.10	8.1	864	13.4	15.40	6.94	47	17.2	266	2.7
SMC-17	35.357557	-107.807733	4/1/2009	14.14	3.18	1980	195.0	7.57	7.8	1100	16.34	18.02	4.91	87.7	5.53	301	3.8
SMC-18	35.348290	-107.803197	4/1/2009	13.18	0.18	1289	-55.9	7.28	7.7	732	10.74	11.83	4.83	89.9	14.8	136	8.1
SMC-20	35.349029	-107.779781	3/31/2009	13.74	2.5	589	-13.7	7.05	7.6	504	6.71	9.01	14.65	92.3	15.8	67.9	5.9
SMC-21	35.363551	-107.769202	3/31/2009	12.96	2.30	2870	57.1	6.84	7.4	3320	15.24	53.11	55.41	536	183	257	4.8
SMC-22	35.325185	-107.826384	3/31/2009	16.56	5.50	7078	40.2	9.29	9.2	506	6.32	8.38	14.05	1.09	0.08	191	0.5
SMC-23	35.345152	-107.786056	3/30/2009	12.64	0.39	3	82.0	6.97	8.4	440	5.19	6.70	12.71	7.07	1.44	143	0.5
SMC-24	35.344586	-107.785136	3/30/2009	12.26	0.78	3221	40.0	7.11	7.3	3310	47.69	47.97	0.29	509	138	254	6.4
SMC-25	35.347131	-107.783340	3/30/2009	10.68	0.83	3110	78,7	7.05	7.8	504	6.86	8.38	9.94	64.9	8.26	102	1.0
SMC-26	35.346584	-107.774666	3/31/2009	13.69	7.29	721	68.1	7.64	7.9	572	7.92	9.96	11.40	48.7	8.35	156	2.3
SMC-28	35.348787	-107.767434	4/2/2009	16.98	1.61	714	101.7	7.50	7.8	378	5.35	6.28	7.98	52.4	6.47	70.1	3.3
SMC-30	35.336706	-107.654231	4/2/2009	10.88	4.40	130	453.0	6.84	7.3	254	3.36	4.32	12.46	51.5	7.26	24.3	3.6
SMC-31	35.335064	-107.638226	4/2/2009	10.1	0.12	969	-11.6	7.37	7.9	500	7.44	9.06	9.85	36.2	7.82	151	1.6
SMC-32	35.354520	-107.794613	4/1/2009	13.38	0.10	2591	-61.9	7.00	7.4	1630	26.86	27.05	0.36	316	72.3	118	7.9
SMC-33	35.321455	-107.817586	4/1/2009	15.42	2.25	2478	59.5	7.12	7.5	1490	22.72	24.76	4.30	225	24.8	262	3.6
SMC-34	35.332654	-107.802743	4/1/2009	n/a	n/a	n/a	n/a	n/a	7.5	1780	26.78	29.55	4.92	247	39.3	317	7.8
Average values	n/a	n/a	n/a	13	5	1926	50	7.58	7.8	1369	18.7	21.9	8.37	176.5	40.6	221.7	4.2

Table 10. Summary of data values describing: the sample number; field parameters; individual and average chemical values; and isotopic results for the 2009 San Mateo Creek set of ground water samples (p. 2 of 3).

Sample Number	Cl (mg/L)	SO$_4$ (mg/L)	HCO$_3$ (mg/L)	Ag (µg/L)	Al (µg/L)	As (µg/L)	Ba (µg/L)	Be (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe (µg/L)	Hg (µg/L)	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	NO$_3$+NO$_2$ (mg/L)	Pb (µg/L)
EPA MCL						10	2000	4	5		100	1300	4		2				10	15
NM WQCC	250	600		50	5000(i)	100	1000		10	50(i)	50	1000	1.6	1000	2	200	1000(i)	200(i)	10	50
SMC-03	32	369	272	<10	<100	2.9	11.9	<5	<5	<20	<10	<20	0.39	<25	<0.2	<5	<50	<20	4.12	<2
SMC-04	33	200	284	<10	<100	5.1	5	<5	<5	<20	<10	<20	1.18	<25	<0.2	<5	<50	<20	0.82	<2
SMC-05	27	105	308	<10	<100	3.2	5	<5	<5	<20	<10	<20	1.28	<25	<0.2	<5	<50	<20	0.86	<2
SMC-07	2.5	168	243	<10	<100	4	18.7	<5	<5	<20	<10	<20	0.76	<25	<0.2	<5	<50	<20	0.02	<2
SMC-08	78	911	10	<10	<100	<2	39.4	<5	<5	<20	<10	<20	<0.25	2740	<0.2	101	<50	<20	0.05	<2
SMC-09	48	2070	168	<10	<100	3.4	5	<5	<5	<20	<10	<20	0.36	<25	<0.2	<5	<50	<20	22.80	<2
SMC-10	47	2110	170	<10	<100	3.2	31.9	<5	<5	<20	<10	<20	0.56	<25	<0.2	<5	<50	<20	21.20	<2
SMC-11	55	1580	188	<10	<100	21.5	11.9	<5	<5	<20	<10	<20	0.31	<25	<0.2	<5	<50	<20	0.02	<2
SMC-12	125	955	210	<10	<100	22.8	11.3	<5	<5	<20	<10	<20	0.91	<25	<0.2	<5	<50	<20	11.50	<2
SMC-13	59	1610	180	<10	<100	37.7	67	<5	<5	<20	<10	<20	0.5	<25	<0.2	11.5	<50	<20	18.60	<2
SMC-14	58	535	246	<10	<100	4.7	12.5	<5	<5	<20	<10	<20	1.08	28.4	<0.2	23.8	<50	<20	2.36	<2
SMC-16	25	323	359	<10	<100	1	29.2	<5	<5	<20	<10	<20	1.68	168	<0.2	57	<50	<20	0.02	<2
SMC-17	11	656	139	<10	<100	10	5	<5	<5	<20	<10	<20	1.25	112	<0.2	53.6	<50	<20	1.45	<2
SMC-18	10	370	167	<10	<100	<2	27.5	<5	<5	<20	<10	<20	0.29	86.9	<0.2	75.7	<50	<20	0.02	<2
SMC-20	15	96	260	<10	<100	4.7	5	<5	<5	<20	<10	<20	<0.25	<25	<0.2	56.8	<50	<20	1.08	<2
SMC-21	42	546	153	<10	<100	<2	21.3	<5	<5	<20	<10	<20	0.46	<25	<0.2	128	<50	<20	9.38	<2
SMC-22	27	100	206	<10	<100	21.5	36	<5	<5	<20	<10	<20	1.27	<25	<0.2	<5	<50	<20	1.86	<2
SMC-23	33	49	192	<10	<100	3.1	54.3	<5	<5	<20	<10	<20	0.43	45.2	<0.2	<5	<50	<20	4.43	<2
SMC-24	50	2070	172	<10	<100	5.3	11.1	<5	<5	<20	<10	<20	0.63	<25	<0.2	<5	<50	<20	20.20	<2
SMC-25	26	144	181	<10	<100	11.8	13.2	<5	<5	<20	<10	<20	1.43	<25	<0.2	<5	<50	<20	5.67	<2
SMC-26	13	135	280	<10	<100	2.5	13.6	<5	<5	<20	<10	<20	1.04	<25	<0.2	<5	72.8	<20	6.28	<2
SMC-28	2.5	144	136	<10	<100	5	5	<5	<5	<20	<10	<20	0.69	<25	<0.2	<5	<50	<20	1.11	<2
SMC-30	2.5	12	184	<10	<100	<2	5	<5	<5	<20	<10	<20	0.41	<25	<0.2	<5	<50	<20	0.11	<2
SMC-31	7	120	286	<10	<100	<2	15.4	<5	<5	<20	<10	<20	0.98	27.4	<0.2	88.4	<50	<20	0.02	<2
SMC-32	33	1100	184	<10	<100	<2	5	<5	<5	<20	<10	<20	<0.25	1650	<0.2	<5	1150	<20	0.02	<2
SMC-33	46	899	153	<10	<100	21	28.1	<5	<5	<20	<10	<20	0.73	<25	<0.2	6.8	<50	<20	9.62	<2
SMC-34	53	1080	163	<10	<100	29	288	<5	<5	<20	<10	<20	0.52	<25	<0.2	<5	<50	<20	6.15	<2
Average values	35.6	684	203	<10	<100	8.5	29.0	<5	<5	<20	<10	<20	0.71	188.7	<0.2	66.4	<50	<20	5.55	<2

Table 10. Summary of data values describing: the sample number; field parameters; individual and average chemical values; and isotopic results for the 2009 San Mateo Creek set of ground water samples (p. 3 of 3).

Sample Number	Sb (µg/L)	Se (µg/L)	Tl (µg/L)	V (µg/L)	Zn (µg/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	^{226}Ra (pCi/L)	^{228}Ra (pCi/L)	U (µg/L)	^{238}U (pCi/L)	^{235}U (pCi/L)	^{234}U (pCi/L)	∂ ^{2}H per mil (‰)	∂ ^{18}O per mil (‰)	∂ ^{13}C per mil (‰)	∂ ^{34}S per mil (‰)
EPA MCL	6	50	2			15	50	5	5	30							
NM WQCC		50			10000			30	30	30							
SMC-03	<2	22.1	<2	<20	28.9	5.6	5	0.01	<0.08	11	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-04	<2	5.8	<2	<20	<20	17.4	5.2	0.08	0.15	20.6 [19]	[5.61]	n/a	[11.1]	n/a	n/a	n/a	n/a
SMC-05	<2	4.6	<2	22.3	<20	20.8	10.3	0.05	<0.17	26.2 [26]	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-07	<2	<2	<2	<20	70.9	8.2	6.8	1.61	0.87	2.5 [2]	0.6 [0.7]	0.1	4.6 [4.03]	-98.3	-13.12	-11.06	-9.25
SMC-08	<2	3.8	<2	<20	<20	6.7	1.5	0.02	0.89	<2 [9]	2.8	0.2	3.9	-57.8	-8.17	-7.80	-6.12
SMC-09	<2	36.5	<2	<20	209	7.9	6.7	0.31	0.28	40.7 [21]	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-10	<2	32.1	<2	<20	81.9	1.3	3.9	0.01	0.36	30.9	0.04	0.01	0.1	-63.9	-8.51	-7.96	-3.96
SMC-11	<2	367	<2	<20	<20	91.3	82.7	0.16	0.76	228 [200]	63	2.8	78.1	-76.7	-10.04	-7.86	-24.97
SMC-12	<2	382	<2	38.3	481	66.8	29.5	0.01	0.52	163 [150]	52 [44.8]	2.3	61.9 [54.6]	-70.8	-9.36	-6.00	-11.11
SMC-13	<2	618	<2	<20	<20	121	83	0.07	0.28	240 [220]	64.3	3.2	75.8	-72.7	-9.89	-5.57	-21.20
SMC-14	<2	52.9	<2	<20	<20	14	9.7	<0.01	0.45	23.2 [21]	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-16	<2	<2	<2	<20	<20	0.9	4.6	0.28	0.44	2.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-17	<2	49	<2	<20	959	58.8	33.3	0.14	0.46	99.5 [85]	[27.1]	n/a	[44.9]	n/a	n/a	n/a	n/a
SMC-18	<2	3.6	<2	<20	<20	10.9	14.6	1.35	0.83	<2 [2]	0.5 [0.52]	0.03	4 [3.73]	-73.3	-9.99	-14.38	1.53
SMC-20	<2	73.6	<2	<20	54.8	46.6	20.6	0.96	1.87	63.9 [58]	17.4	0.9	30.4	-73.6	-9.96	-9.06	-1.84
SMC-21	<2	8	<2	<20	<20	6.5	7.5	0.27	2.4	11.9 [10]	3.3	0.2	6.8	-71.8	-9.84	-6.48	-11.37
SMC-22	<2	26.3	<2	135	<20	33.5	11.7	<0.01	0.11	42.9 [42]	[12.8]	n/a	[22.9]	n/a	n/a	n/a	n/a
SMC-23	<2	27.1	<2	<20	<20	6.2	10.9	0.42	0.97	10.1 [12]	3.8	0.3	6.1	-68.9	-9.51	-7.51	-12.07
SMC-24	<2	66.2	<2	<20	<20	20.7	20.1	<0.01	0.33	13.8 [36]	11.8	0.4	15.7	-70.2	-9.00	-7.44	-11.40
SMC-25	<2	13.2	<2	26.5	<20	16	10.4	<0.01	0.51	20.6 [26]	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-26	<2	26.2	<2	<20	20.8	128.3	45.3	0.13	0.24	188 [170]	62.5 [52.9]	3.5	94.6 [82.4]	-68.3	-9.52	-9.34	-0.33
SMC-28	<2	42.6	<2	<20	527	19.4	18.6	0.15	0.34	46.4 [43]	13.5	0.6	19.8	-70.7	-9.78	-8.56	9.09
SMC-30	<2	<2	<2	<20	<20	2	3.1	n/a	0.8	2.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMC-31	<2	<2	<2	<20	268	<0.1	2	0.38	n/a	<2	0.1	-0.02	0.5	-89.2	-12.03	-12.21	n/a
SMC-32	<2	<2	<2	<20	23.3	56	50.3	2.9	3.91	<2 [100]	31.8	1.6	31.3	-71.6	-9.75	-7.82	-15.48
SMC-33	<2	268	<2	<20	<20	72.1	62.5	0.13	0.5	166 [150]	46.7 [42.7]	2.5	59.9 [53.5]	-79.0	-10.20	-7.03	-8.21
SMC-34	<2	434	<2	<20	<20	56.2	46.4	0.27	0.46	117 [100]							
Average values	<2	95.1	<2	<20	<20	33.2	22.5	0.37	0.75	58.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	SLD radiochem data in brackets [ ]: U, 238U, & 234U.																

Table 11. Environmental issues, data gaps, and suggested solutions for the San Mateo Creek area, New Mexico (p. 1 of 1).

Environmental Issue	Data Gap	Suggested Solution
1 Conceptual model of the hydrogeology of the SMC area, particularly the alluvial channel, is incomplete and poorly understood.	Surface-subsurface geology-hydrology not well known.	Geologic mapping + geologic cross sections to understand San Mateo Fault Zone, depth-width of alluvial channel, bedrock units cut by alluvial channel in hydraulic communication with Qal aquifer.
2. Conceptual model of the hydrology part of the SMC area is unknown. Is there seasonal flux in Qal aquifer SWLs? Is there still surface flow in SMC channel? Is there still recharge to Qal aquifer?	Static water levels (SWLs) not available: have levels returned to pre-mining conditions?	Manual + transducer/logger SWL data needed at various depths at various positions along + away from Qal channel. New borings & wells that also support No. 1 above.
3. Geochemical characterization of ground water systems off to good start, but hampered by existing wells: no choice but to sample existing wells. Wells not located or constructed for investigation objectives.	No control over well locations & screen zones to identify & sample discrete zones/aquifers w/ confidence-reliability.	Focus exploratory drilling, sampling, characterization, monitoring on Qal aquifer. Above-below state road 605-509 junction and above & below Qal well cluster north of HMC site. Conduct exploratory drilling in transect fashion in Qal channel above, across, & below areas of elevated water quality parameters (TDS, SO_4, NO_3, U, Se).
4. Geochemical understanding of sources of elevated major ions, trace metals unknown-poorly understood. Suspect-assume that legacy U mining-milling is source of elevated analytes.	Have not determined source of elevated TDS, Na, SO_4, NO_3, U, & Se.	Need more ground water sampling points w/ better control of location & discrete sample intervals. Confirm and expand geochemistry parameters: Nitrogen $\delta^{15}N$, sulfur $\delta^{34}S$, uranium isotopes $^{234}U:^{238}U$; species or complexes of U, Se, Mo, Fe?
5. Confirm application of U isotopes to determine source of elevated U in Qal aquifer; source of Se, source of SO_4 using $\delta^{34}S$ isotope.	Need proof of concept that ratio $^{234}U:^{238}U$ can distinguish anthropogenic component.	Measure U isotopic ratio at 12-15 well locations to prove-disprove U milling raffinate waste water in Qal aquifer hypothesis. UNM, NM Tech, EPA, USGS, & possibly LANL to perform isotopic analysis & geochemical interpretation.
6. Mineralogy of Qal aquifer materials unknown. Do metals U + Se adsorb-desorb to gravels, sand, silt, clay layers? if clay layer surface coated w/ minerals – do metals mobilize downstream until they adsorp? If SWLs drop or rise, do metals go out of or back into solution?	Mineralogical data on Qal aquifer materials not available.	Collect various sieve size samples from various locations-depths for x-ray diffraction & geochemical assay to determine composition. Determine materials or zones that contained elevated metals and why.
7. Geochemical modeling of ground water should be long term objective to predict water quality changes, mixing of end members to predict resultant water.	USGS or university research modelers not available yet.	Circulate draft ground water report & future investigation work plans to agencies-entities with modeling capacity to seek-obtain their involvement.

Table 12. Comparison of average values of chemical parameters between ground water sample sets, Bluewater and San Mateo Creek areas, Grants Mineral Belt, New Mexico.

Chemical parameter	Temperature (T) °C	Dissolved Oxygen (DO) mg/L	Specific Conductance (SC) µS/cm	Oxidation Reduction Potential (ORP)	Field pH	Lab pH	Total Dissolved Solids (TDS) mg/L	Total anions meq/L	Total cations meq/L	Charge balance error	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)	Ag (µg/L)
SMC averaged values w/o SMC-03, -04, & -05 & w BW-35	13.45	5.1	2092	45.9	7.49	7.7	1432	19.57	22.99	8.81	189.5	43.9	230	4.6	37	729	196	<10
BW averaged values w/o BW MWs & w/ SMC-03, -04, & -05	15.3	5.7	1475	117.4	7.07	7.4	1051	15.58	17.21	5.25	153.3	44.6	132	5.2	69	422	291	<10
Numerical difference between chemical averages for each group of samples	-1.85	-0.6	617	-71.5	0.42	0.3	381	3.99	5.78	3.56	36.2	-0.7	98	-0.6	-32	307	-95	0

Chemical parameter	Al (µg/L)	As (µg/L)	Ba (µg/L)	Be (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe (µg/L)	Hg (µg/L)	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	NO_3+NO_2 (mg/L)	Pb (µg/L)	Sb (µg/L)	Se (µg/L)
SMC averaged values w/o SMC-03, -04, & -05 & w BW-35	<100	8.8	30.9	<5	<5	<20	<10	<20	0.68	202.8	<0.2	71.5	no lab data	<20	5.91	<2	<2	101.8
BW averaged values w/o BW MWs & w/ SMC-03, -04, & -05	<100	2.8	20.1	<5	<5	<20	<20	<20	0.4	24.1	<0.2	<5	<2	<20	3.3	<2	<2	8.8
Numerical difference between chemical averages for each group of samples	0	6	10.8	0	0	0	0	0	0.28	178.7	0	69	0	0	2.61	0	0	93

Chemical parameter	Tl (µg/L)	V (µg/L)	Zn (µg/L)	Gross alpha (pCi/L)	Gross Beta (pCi/L)	^{226}Ra (pCi/L)	^{228}Ra (pCi/L)	U (µg/L)	^{230}U (pCi/L)	^{235}U (pCi/L)	^{234}U (pCi/L)	δ^2H per mil (‰)	$\delta^{18}O$ per mil (‰)	$\delta^{13}C$ per mil (‰)	$\delta^{34}S$ per mil (‰)
SMC averaged values w/o SMC-03, -04, & -05 & w BW-35	<2	<20	114.7	34.2	23.4	0.41	0.78	67.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BW averaged values w/o BW MWs & w/ SMC-03, -04, & -05	<2	<20	50.5	8.3	8.1	0.1	0.2	12.4	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Numerical difference between chemical averages for each group of samples	0	0	64.2	25.9	15.3	0.31	0.58	54.9	0	0	0	0	0	0	0